D1.1: TREASURE reference framework

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Technical References

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EXECUTIVE SUMMARY

D1.1. is meant to report activities carried out within WP1 and, more specifically, in Task 1.1 – TREASURE reference framework (hereinafter: T1.1). The ultimate goal of T1.1 is to develop the TREASURE reference framework, i.e. the reference structure all the following TREASURE development are referred to, including methodologies, software solutions, technologies and demonstrations. According to the Description of Activities, the developed framework represents a conceptual starting point especially for WP2 advisory methodologies, for WP4 platform design and implementation, and a valuable input for the other two tasks of WP1, T1.2 dealing with software requirements and specifications and T1.3 concerning the preliminary design of industrial use cases. The here-proposed architecture can be further revised in the following months of the project shall requirements evolve or if needs change since it is represented using a web platform (Miro) made accessible to all the project partners. The Deliverable describes the reference framework considering three complementary levels of analysis: the project, where the interactions between WPs, tasks, and specific activities are mapped; the partners' roles and their relevance in the industry; and the automotive supply chain, with the goal to provide a preliminary positioning of the project on existing Circular economy practices in the automotive supply chain. The Deliverable presents the context, the purpose of the project and of Task T1.1, and how D1.1 is structured (Chapter 1). Next (Chapter 2), methods and tools used to achieve the results required by the task are presented, such as the Miro board and workshops with other partners. Then, in Chapter 3, the relationships with the project activities at WP level (considering timing and logical relationships), at task level, and at key enabling technologies level are presented. Critical issues of the project found so far are also highlighted. In Chapter 4 a comparison is made between the state of the art (SoA) and TREASURE envisaged results, highlighting how the project relates and supports the identified trends.

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1. Introduction

1.1. Purpose, context, and scope

TREASURE (leading the TRansition of the European Automotive SUpply chain towards a circulaR futurE) project wants to support the transition of the automotive sector towards Circular Economy (CE) practices, by providing a demonstration of the improvement CE adoption could introduce under both the business and the technological points of view.
Even if companies in the automotive sector are investing money to shift their business towards more sustainable mobility concepts, still a set of barriers are limiting the potential benefits of CE practices adoption. In TREASURE it is intended to investigate techniques to maximize the recovery of critical, high-value materials from End of Life (EoL) automotive electronic components and then develop techniques to produce new components (Beginning of Life - BoL) of equal quality and designed to facilitate the disassembly and recycling processes once they reach again the EoL. A first identified problem from a technological point of view concerns many issues to be solved to functionally recover materials from cars (e.g., to reuse recovered materials for the same purpose they were exploited originally). Innovative recovery processes require not only a focus on the EoL practices, but a redefinition of products since the BoL phases, by rethinking together with End-of-Life Vehicles (ELVs) recovery techniques also new eco-design practices, with easiness of disassemble and recycle specifications. Consequently, BoL and EoL stages must be interconnected. Related to this point, the second identified problem arises: from an information sharing perspective, the limited collaboration among actors involved in traditional automotive value chain is slowing down the sector transformation. Indeed, data about car parts materials are on strictly protected databases, accessible only by authorized actors, thus it is not possible to exploit them to optimize ELV management processes. Reverting the flow, information about ELV management processes, even if available, are not reaching the carmakers, excluding the possibility to improve design phases.
TREASURE intends to act on ELV management processes, both creating new supply chains around ELVs by focusing on a circular exploitation of raw materials embedded into cars and exploiting Industry 4.0 technologies on the technological side. Moreover, TREASURE tries to fill in the existing information gap among automotive actors, both at design and EoL stages.
Considering what stated above, TREASURE project wants to pursue the following main results:

- The development of an AI-based scenario assessment tool supporting the development of circular supply chains in the automotive sector.
  The tool is designed for all the companies involved in current automotive value chains, such as car parts suppliers, car manufacturers, car dismantlers, car shredders, up to consumers, indeed considering the value chain up to its final actors.
  The applications of the tool, within and outside TREASURE context, are the quantification of CE adoption's implications on the whole value chain, and the exploitation of new information sharing channels among all stakeholders, both in forward and backward directions, ensuring secure access and confidentiality. This tool will contain a series of modules, one for each category of actor in the value chain, such as the module for dismantler (containing aggregated information indicating the most valuable car parts, the disassembly times, and tools); the module for the recyclers (containing indications of best recycling routes and processes for optimum recovery); AND The module for automotive manufacturers (containing aggregated information for the eco-design). The platform will also provide consumer information such as a resource recycling efficiency label.
- The demonstration of the benefits coming from the adoption of CE principles in the automotive sector, by representing a set of success stories in three key value chains of the automotive industry (focusing on SMEs):

1) dismantlers/shredders: TREASURE will demonstrate how the adoption of CE principles and I4.0 technologies can increase the overall circularity performance of EoL practices. The demonstration use case 1 is the "*Disassembling wasted car electronics through (I4.0-based) semi-automated processes"*, which will support, and will be supported by, the development of disassembly module of TREASURE platform;
2) recyclers: TREASURE will demonstrate how the adoption of CE principles can enable circular supply chains, by increasing quality, market value and alternative exploitation of secondary materials in the automotive sector. The demonstration use case 2 is the "*Recovering valuable materials from wasted car electronics through bio-hydrometallurgical processes*", which will support, and will be supported by, the development of recyclability module of TREASURE platform. The recycling module (based on advanced recycling flowsheet simulation models) will compare bio-hydrometallurgical processing with existing metallurgical infrastructures by not only assessing recycling/recovery rates, but also taking into consideration losses and exergy created, hence providing a sound framework for selection of best available technology processing of disassembled cars parts (focusing on modular recycling);
3) manufacturers: TREASURE will study potentials for circular economy options, will develop technology and make prototypes to showcase the gain in circularity from structural printed electronics compared to conventional one. The demonstration use case 3 is the "*Prototyping in-mold/structural electronics starting from materials embedded in wasted car electronics*", which will support, and will be supported by, the development of eco-design module of TREASURE platform.

- The integration of Key Enabling Technologies (KETs) for the efficient design of car electronics and subsequent disassembly and materials recovery.
  TREASURE wants to check the potentialities related to the adoption of four kinds of KETs (all pertaining to the advanced manufacturing systems category) in EoL practices, such as Artificial Intelligence (AI), Digital Twin (DT), Cyber-Physical Systems (CPS), cobots, bio-hydrometallurgical materials recovery processes, technology of structural electronics designed for circularity. Potential benefits in terms of sustainability and circularity performance enhancement will be tested through the scenario assessment tool application.

The solution proposed by TREASURE will be developed to achieve the above objectives within the project context, but at the same time without excluding the possibility to be adopted also outside TREASURE consortium. With this ambition, a reference framework must be defined, which covers different levels of exploitation of TREASURE solution, as described in the following section.

1.2. Content and structure of the deliverable

D1.1 is the deliverable associated with task T1.1, which is the first task of the project, the one concerning the definition of a multi-dimensional Reference Framework structured in different levels:

- <u>Project</u> level – define the project vision, the project architecture, the information flows, the knowledge, and the resources needed in each activity. Chapter 3 is entirely dedicated to building this framework, together with §4.2.1 and §4.2.2 of Chapter 4.
- <u>Partners and industry</u> level – partner's roles are highlighted both within the project and as possible future exploiters of project results in the automotive supply chain. No chapters are present in the deliverable that cover this framework; this activity will be completed by month 6 (M6) and published as a reference for all partners on Miroboard.

- <u>TREASURE vs CE in automotive</u> level – how the project results could be exploited for other CE themes in the automotive level (e.g., the gathered data could be exploited also for other CE business models (BMs)). Chapter 4 covers this framework.

According to the proposal, the main goal of this task is to define the project reference framework that will act as the backbone structure of the project activities.

Within the context of the project level, two main frameworks were developed:

- The project architecture framework;
- The value chain digitalization framework;

plus a framework that can be located in between the project level and TREASURE VS CE in automotive level:

- The circularity framework.

The *project architecture reference framework* links work packages and tasks to each other, highlighting inputs, outputs, and resources. This framework puts in direct connection all the project activities, identifies their timing, makes explicit the role of the individual partners, and provides each contributor with a kind of agenda in which it is marked what product they are expected to produce, by when and to whom it should be sent and, at the same time, what inputs they should expect from which partner (task), and by when. §3.1 and §3.2 are dedicated to the construction of this framework.

The *value chain digitalization reference framework* allows highlighting the data flows in the various phases of the project and in the interactions with the platform. No chapter in this deliverable covers this framework; this framework will be investigated in D1.2.

Finally, the *circularity reference framework* is responsible for highlighting how materials circulate through the various disassembly, recycling and prototyping processes at the simulation, laboratory and industrial level, and how TREASURE demonstrators can enhance best circularity practices in automotive value chain, opening the discussion on results exploitation and placement along the current and future mobility. §3.2.3 is dedicated to the construction of this framework, as well as §4.2.1 and §4.2.2.

Concerning the project level, only the project architecture reference framework and the circularity reference framework are presented in this version of the deliverable. Moreover, the second level of reference framework, the partner and industry level, will not be covered as well in this deliverable, as explained in §3.1.1.

In Chapter 2, the references, tools, and methodologies used to develop TREASURE reference framework are described. In Chapter 3, the project reference framework is structured by defining the relationships among project activities, highlighting open points and criticalities, mapping interdependences, and showing how demonstration activities locate the project in the transformation scenario of circular automotive value chain. Indeed, in Chapter 4, a study of State of the Art (SoA) on existing CE practices, business models and initiatives in the automotive industry is presented, with focus on the update of SoA with respect to the Description of Activities (DoA). This analysis that will serve as input to WP8, has been carried out in order to answer to the requirement, mentioned also in the description of the task T1.1 to identify the reference structure of the business models. TREASURE contribution has been compared to other CE frameworks, identifying gaps and additional exploitation opportunities, and placing results in the circular automotive supply chain to be further explored in the "Exploitation, standardization and business model" work package (WP8).

2. Tools used/research methodology

This chapter is meant to describe the methods used to build the project architecture reference framework that aims at depicting the links between work packages and tasks and highlight inputs, outputs, and resources. The starting point for the project architecture reference framework definition is the information included in the DoA. That information is structured via the methodology defined in §2.1 that describes the formalism exploited to transfer the DoA indications into a graphic layout that constitutes the visual reference framework for the project. The graphicisation of the DoA is then developed with the use of a Miroboard, outlined in §2.2, and exploited throughout the task T1.1 to carry out two workshops, whose structures and intents are specified in §2.3 and §2.4.

2.1. Project architecture reference framework graphic formalism

In order to structure the huge amount of information contained in the DoA and identify in a rapid and schematic way the interconnection of the TREASURE activities, the content of the DoA has been represented through the graphical layout shown in Figure 1 and described hereafter.

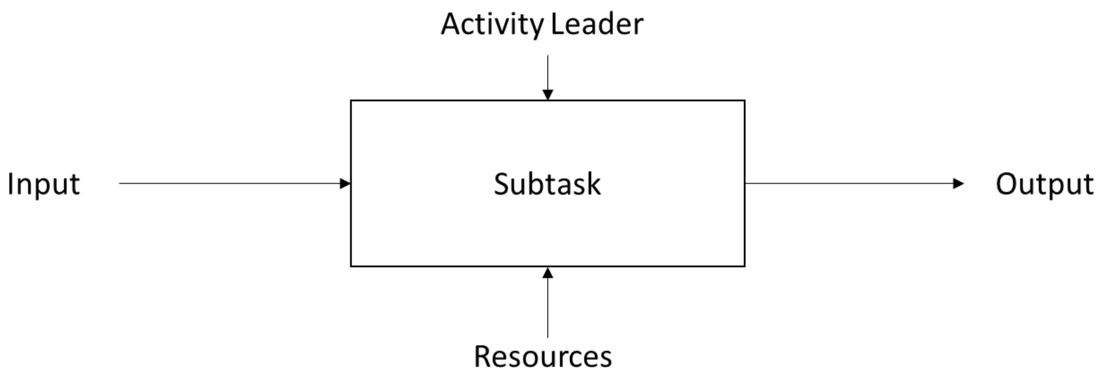

Figure 1. Graphical representation of DoA activities

In order to provide a deeper understanding of the activities to be carried out during the project, starting from the typical structure of the work plan reported in the DoA made by Work Packages (WPs) and Tasks, each task has been further divided into sub-tasks. These sub-tasks have been identified from the task description in the DoA. Each sub-task can be considered as the unit activity to be carried out in order to manage and achieve the task's objectives. From the graphical point of view, a short description of the sub-task is contained in a squared box, that has one arrow coming out and three arrows entering into the Sub-task box. Each arrow brings additional information about sub-task deployment:

- The arrow **entering the top** of the box represents the activity leader. It could correspond to either the task leader or a contributor partner that is the responsible for the concrete implementation of the sub-task activity;
- The arrow **entering the bottom** of the box lists the resources exploited to carry out the sub-task. With the term resources, it is intended the set of different possible elements that are used to achieve the task's results such as technologies, databases, software, standards…;
- The arrow **entering the left side** of the box contains the inputs needed to the activities coming from other sub-tasks. The type of inputs could be both physical (such as materials, documents…) and informative (such as data, results of previous analysis…);

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- The arrow **coming out from the right side** of the box is the output provided by the sub-task, which is in turn the input of one or more other sub-tasks. Thus, outputs have the same characteristics of inputs (both physical and informative).

For instance, the job description of T1.1 is stated as follows, but enriched with the indication of the three subtasks identified for T1.1:

> *"***Task 1.1: TREASURE reference framework (Leader: SUPSI**, Contributors: POLIMI, UNIZAR, TNO, M1-M6)
>
> *(***T1.1.1)** T1.1. will develop the TREASURE reference framework. This framework will constitute the reference structure for the subsequent design, implementation, and integration of TREASURE in terms of methodology, software platform, business model, standardization, and demonstration activities. **(T1.1.2)** The developed framework will represent the conceptual starting point for the definition of the TREASURE assessment and advisory methodologies (WP2), for the platform design and implementation activities carried out in WP4, and of the relevant interactions among project outputs. **(T1.1.3)** Even though the framework will be developed in the first period of the project, it will evolve together with it to manage emerging needs and constraints, for instance arising from the interactions with stakeholders."

The sub-activities within T1.1 have been represented in Figure 2 using the formalism described. For each of them the resources, the partners involved, the inputs and the outputs have been highlighted. T1.1.1 is led by SUPSI, in collaboration with UNIZAR, TNO, POLIMI, according to the DoA, but also with the help of MARAS and UNIVAQ, and consists in the development and validation of the graphical layout of the activities, exploiting as resources the DoA, the Miroboard and a workshop. The outputs are the project level frameworks of activities and circularity, which are the inputs for the T1.1.2. In this following step, the resources used are again a Miroboard and a second workshop to gather preliminary information about data flows and software development to validate the project level – value chain digitalization framework, and to provide inputs to T1.2 on software high-level architecture. Moreover, a review on the SoA was carried out to define the third level of the reference framework, namely the TREASURE VS CE in automotive level, which provides input to T8.1, T8.2, T8.6 exploitation tasks. The outputs of T1.1.1 and 1.1.2 constitute the D1.1: T1.1.1 covers chapter 2, while T1.1.2 chapter 3. T1.1.3 is not covered by D1.1, as explained in §3.1.1, but will be integrated in future deliverables, is related to both the *Partners and industry level framework* and the update of the reference framework throughout the project by using the Miroboard. All the partners will be involved in these activities.

Repeating this procedure for all the tasks of the project enables to provide a view of the project level architecture, as described in Chapter 3.

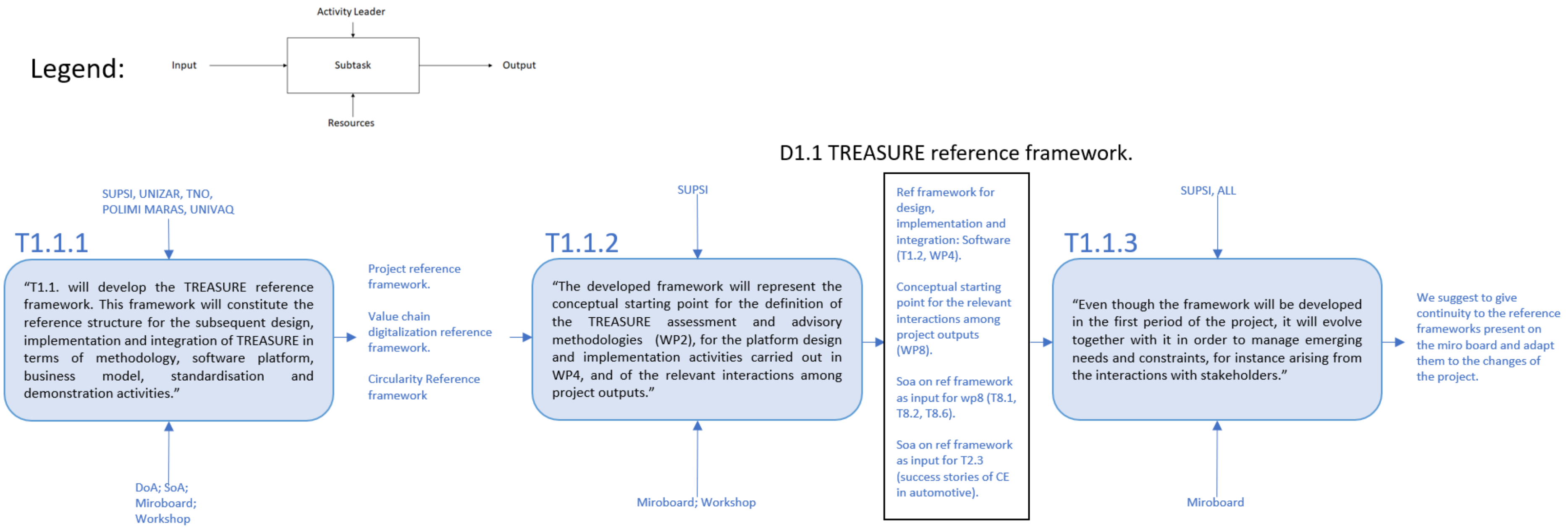

Figure 2. T1.1 sub-activities relationships

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2.2. Introduction to Miroboard use and scope

The structure coming from the formalism described in the above section has been developed in Miroboard[2], a web-tool that provides editable whiteboards. Indeed, this tool relies on a dispersion board with different functionalities supporting collaborative working: graphical elements (arrows, boxes), possibility to add comments, images, etc. are used to represent the various flow charts and add all kinds of details to them.
Two frames were developed in Miroboard and shown in Figure 3: both frames represent the same scheme of sub-task activities linked by their input/output relationships as in §2.1. The first frame aims at focusing the attention on the work packages level interactions, by highlighting how the sub-tasks are divided in work packages and how work packages share information one with each other. While the first frame is meant to provide a high-level overview of the project, the second frame instead is thought to go into detailed interactions at sub-tasks levels.
The choice of Miroboard relies on its following main advantages:

- Its greater flexibility allows to add and edit a large amount of content and, therefore, to easily represent the "big picture" of the project activities;
- It allows a greater collaboration with partners, since everyone can join the board, and add and edit contents. The board was indeed exploited to carry out two workshops (see §2.3 and §2.4), aimed at discussing and sharing with the consortium the big picture of the project architecture;
- It gives the opportunity to have a single reference point throughout the duration of the project and to make the reference framework evolve as the project does.

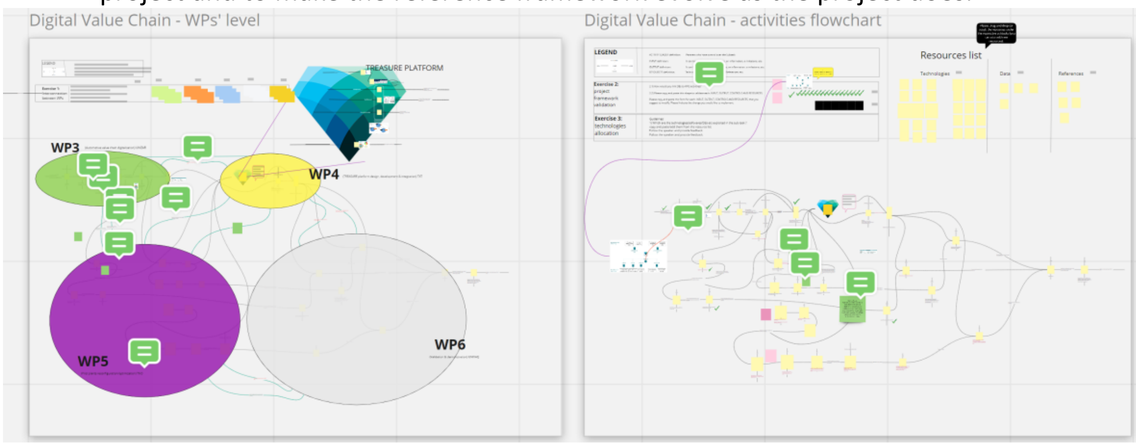

Figure 3. WPs level and Task level frames on Miroboard

2.3. Workshop on WPs and tasks reference framework

In this section, the first workshop is described. It has been organized with all the partners of the consortium, but the main contributions were expected from WPs leaders. It consists of two exercises with guiding questions to be answered, referring both to the graphitization scheme at the two levels of work packages (first exercise) and tasks interactions (second exercise).
In the first exercise, the focus was on describing the various work packages, highlighting key milestones, and mapping the relationships between them. WPs leaders were asked to share and harmonize a common vision, and so validate the project framework at the work packages level. In this first activity of the workshop, the highlighted interconnections among work packages were presented to the participants and the WP leaders were asked to report:

- The main milestones of their work package;

[2] https://miro.com

- The inputs expected from the other work packages;
- The outputs provided to the other work packages.

The participants were also given time and space to note down their concerns or observations directly on the WP framework. The second exercise went into more detail by mapping the relationships between the activities. The partners were asked to go to the sub-tasks they are leader of, and analyze the identified relationships with other sub-tasks. For each single sub-task in each work package, the inputs, outputs and resources, making particular attention to the Key Enabling Technologies use throughout the project, have been validated. Also in this second exercise, the participants were invited to leave any kind of comment over the connection arrows or next to activity descriptors that could help the clarification of the project architecture and the identification of criticalities in the deployment of the activities. The results of the workshop were rearranged and described in Chapter 3.

2.4. Workshop on platform and data flows

From the results of the first workshop, it was found that an additional effort was required to deepen the data flows exchanges, especially in relation to the platform development and use phase. Indeed, the information about the use of databases and the interconnections among work packages and WP4, namely the one dedicated to the platform, are necessary to develop and validate the reference framework for the digitalization of the value chain activities.
For this reason, a second workshop with TXT, which is in charge of the platform deployment, was carried out, and reported in Figure 4. During the workshop, a series of guiding questions were provided to the participants to understand:

- The interaction among the platform modules and the circular advisory tool;
- The role of AI in the platform use phase;
- The database exploitation during the development and the use phases;
- The inputs required and the outputs provided for the development phase;
- The inputs required and the outputs provided for the use phase.

The workshop results will be reported and discussed in other deliverables planned for WP1 (most probably in D1.2) since they are achieved just after this document delivery date.

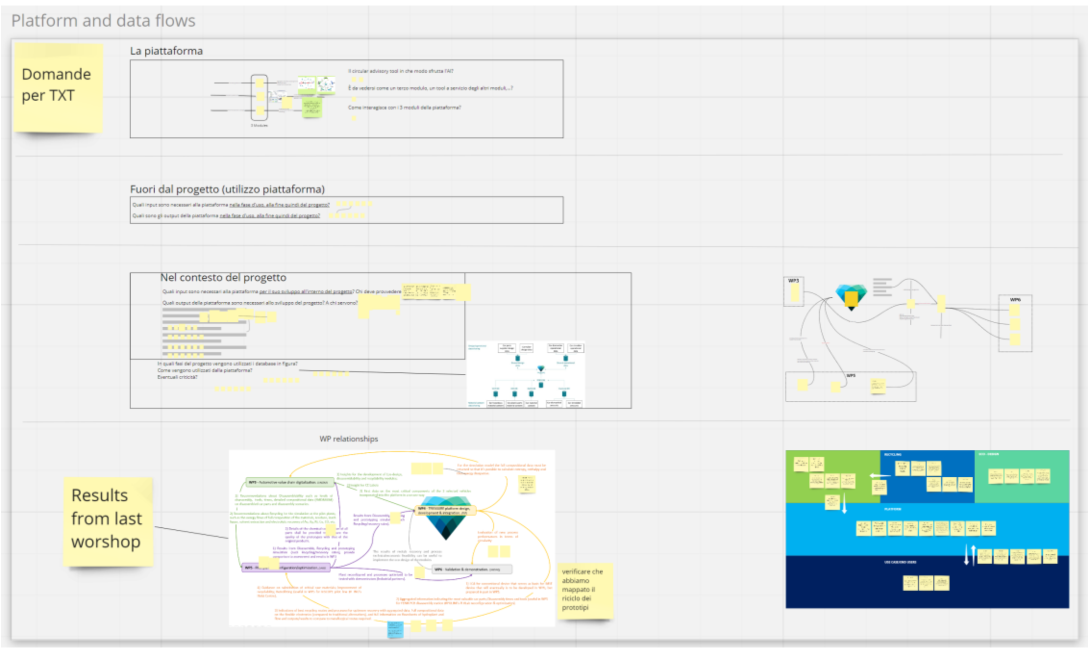

Figure 4. Platform and data flows workshop on Miroboard

3. Relationships between project activities

This chapter is dedicated to the project level. The project architecture reference framework is described by defining interconnections among project activities at two different levels of detail, namely at work packages level and at task level, combining DoA information and workshops results. In §3.1, the interactions among work packages are analyzed under three points of view, the temporal interconnections (see §3.1.1), the logical temporal interconnections (see §3.1.2) and the logical interconnections (see §3.1.3). Criticalities coming out from the arrangement of work packages' relationships were pointed out in §3.1.4. In §3.2, the task level interactions is deepened focusing on the ongoing tasks, highlighting the inputs, the outputs and the resources in §3.2.1, placing Key Enabling Technologies along project activities in §3.2.2 and, at the same time, trying to give an interpretation of the demonstrations activities in view of chapter 4 discussions. Indeed, results from industrial pilot demonstrations will be described underlining their contribution in terms of circularity improvement, placing these results to the automotive value chain.

3.1. Work packages level

The following section concerns the description of the work packages interactions under three perspectives:

- The temporal one, to provide the timeline of the work packages in terms of milestones to be achieved and deliverables deadlines;
- The high-level temporal-logical one, to provide an overview of the main objectives of each work package, establish cause-effect relationships and check that these are consistent with the project time plan;
- The logical one, to provide a picture of the operational work packages and describe the main interconnection flows.

3.1.1. Temporal

Figure 5 shows the project GANTT. Accordingly, TREASURE will last 36 months, during which ten work packages will be developed. The work plan was arranged to properly connect work packages' activities: most work packages run in parallel to allow iterations across them. For instance, WP4 is still running at the WP6 starting month: the platform first version will be validated through the demonstration activities, which in turns will be optimized thanks to the platform outputs, as better explained in §3.1.3. However, these iterative loops require the involved partners to collaborate in a synergic manner in order to achieve a correct and punctual information sharing. For this reason, the mapping of interconnections under temporal as well as logical points of view is fundamental in clarifying the roles and responsibilities and in highlighting criticalities that could arise from uncompleted and/or not on time information flows.
Besides WP1, ongoing activities at M4 are from all the work packages, exception made for TREASURE platform activities of WP4 and for the validation and demonstration activities of WP6, which will start, respectively, at M6 and M18. All activities of WP1, WP2, WP7, WP9 and WP10 already started, together with T3.1, T5.3, T5.5, T8.1 and T8.4.

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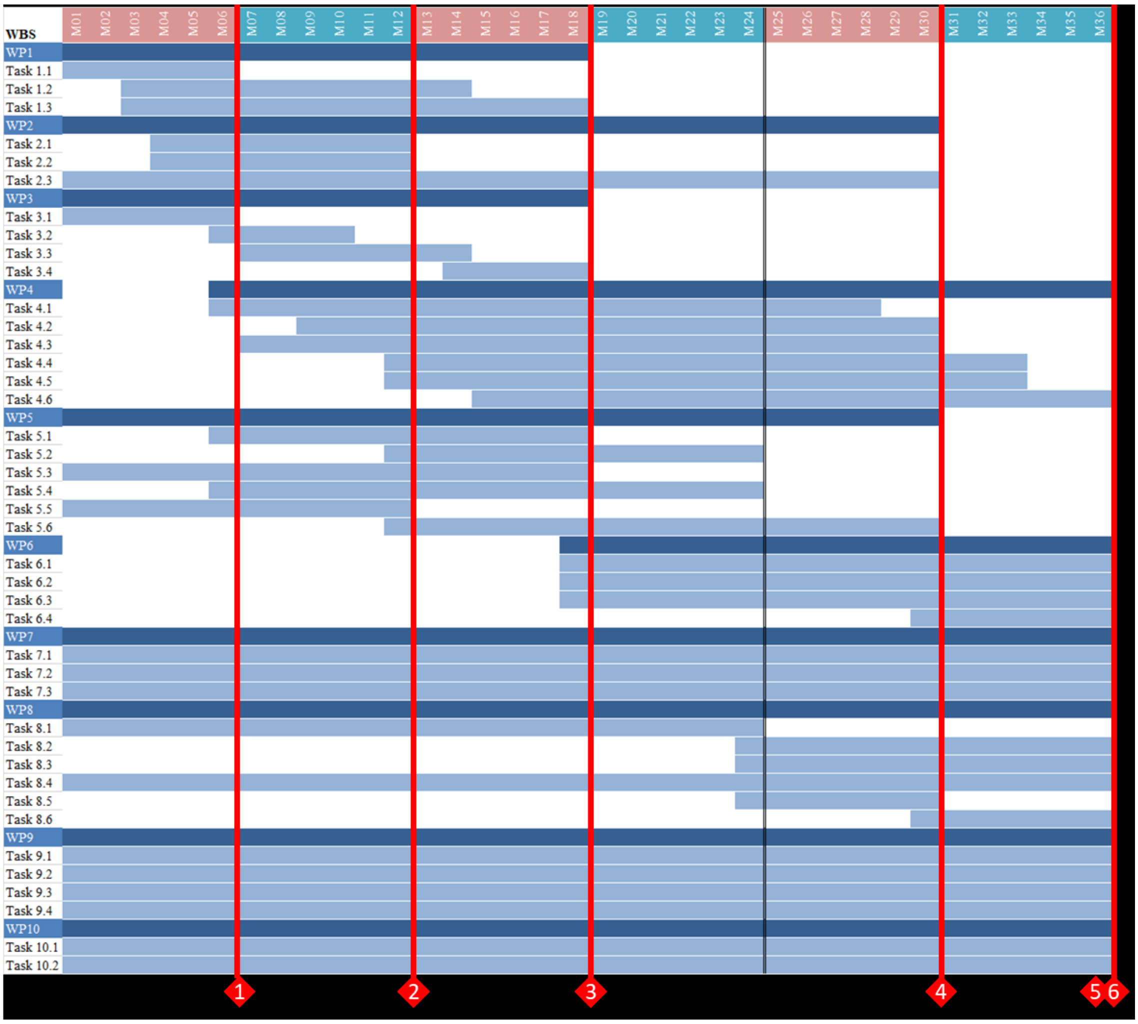

Figure 5. Work plan of the activities

During the workshop, WPs leaders were asked to identify milestones to be achieved during their work packages activities. The discussion allowed identifying milestones that are not formally inside the DoA, but are key elements to get successful outcomes from the project. Table 1 summarizes the work packages milestones in agreement with the results obtained. In the first column, the milestones already provided in DoA were reported, together with the expected month when to achieve them, in the last column. The second column was reserved to the additional milestones highlighted by WPs leaders. For each of them, a matching with the work plan and the deliverables' deadlines has been made in order to get a reasonable due date for milestones achievement and possible criticalities in terms of timing.
It could be highlighted that, for what concerns WP1, the reference framework was expected to be developed and shared with TREASURE consortium at M6, which corresponds to the ending of T1.1 in charge of its creation. However, the deliverable's deadline has been set at M4, which is incompatible with the full deployment of the activities and their integration in an overall picture of the project architecture. Indeed, the activities that will be carried out in M5-M6 will be aimed at:

- further depicting the roles of key partners based on their background knowledge and their possible exploitation of project results, laying the foundation for the "Partners and industry" level framework;
- further investigating possible criticalities for which there is no evidence yet, addressing solutions and responsibility in finding them to provide the clearest overview of the consortium potentialities.

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The additional activities will be integrated in a future version of D1.1, or in another deliverable of the assessment methodology definition (i.e., directly on the D2.1). Beside the opportunity of sharing a common vision with TREASURE partners, as described in §2.2, the reference framework was developed in Miroboard also to try to give continuity to the activities of T1.1 during its working period, in between M4 and M6.

Table 1 Work packages milestones

WP# - Title (WP Leader)	Milestones	Additional milestones	By month
WP1 - Reference framework definition (SUPSI)	Reference framework available		6
		High-level software architecture as a reference for the project	8
		Preliminary description of the use cases highlighting required needed data and missing ones, giving suggestions on how to collect the latter	8
		List of data requirements to be shared with use cases	8
		Map expertise inside and outside the consortium for each area of the framework	6
WP2 - Circularity & sustainability assessment methods integration & application (EDGE)	Circularity and sustainability assessment methodologies and KPIs ready to be adopted		12
WP3- Automotive value chain digitalization (UNIZAR)		Definition of reference SEAT car models; data collection from SEAT to identify critical car parts	6
		Results of disassemblability and recyclability analysis (reference flowsheet and reference simulation tools to be use in the pilots and for platform modules development)	10
		KPIs from physics based recycling standards and validation of the	10

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		recommendation for the assessment tool by the relevant stakeholders	
WP4 – TREASURE platform design, development & integration (TXT)	TREASURE platform (beta version) ready		18
		Technical architecture first version ready	9
		TREASURE Platform first version ready	13
		Platform modules first version ready	15
		Verification and validation of the first version	18
		Technical architecture final version ready	28
		TREASURE Platform final version ready	30
		Platform modules final version ready	33
		Verification and validation of the final version	36
WP5 – Pilot plants reconfiguration/optimization (TNO)	TREASURE pilots simulated, tested, and optimized for automotive applications		30
WP6 – Validation & demonstration (UNIVAQ)	TREASURE pilots validated and demonstrated in real industrial contexts		36
WP7 – Dissemination, communication & clustering (UNIZAR)			
WP8 – Exploitation, standardization and business model (UNIVAQ)	Business model & standardization strategy defined		36
WP9 – Project management (POLIMI)			
WP10 – Ethics requirements (POLIMI)			

3.1.2. High-level temporal-logical

In this section, the temporal framework of the work packages analyzed in §3.1.1 has been put in relation to the main objectives of the work packages in order to establish cause-effect relationships among them. In Figure 6, the mapping of the WPs' contents and objectives on the scheduled timeline has been carried out starting from the information reported in the DoA.

Based on their high-level purpose, the work packages are grouped in three types, corresponding to the three layers in Figure 5.
WP1 to WP4 are the work packages of the first layer "TREASURE methodologies and tools", in charge of providing the project general vision, the platform architecture definition and development. Indeed:

- WP1 and WP2 are the work packages delivering the reference framework and defining the methodology, and form the conceptual foundations for the project;
- WP3 is about digitalization of the automotive value chain, both at BoL and EoL stages, laying the basis for the development of the three platform modules. Indeed, it will develop and apply rigorous physics based models (i.e., recycling simulation models) and calculations (i.e., exergy for criticality) for recyclability and disassembly analysis linked to recycling optimization. The optimization for the system architecture of the physical and metallurgical recycling processes will be linked to improved disassembly strategy, giving a new approach in recycling technology. Moreover, based on what stated above, WP3 will define KPI's to be exploited by the platform modules on the form of physics based recycling standardized labels.
- WP4 is entirely related to the platform, from the high-level architecture development to the implementation and validation.

WP5 and WP6 are in the second layer of "Validation and demonstrations activities on pilot projects":

- WP5 concerns the plants reconfigurations and simulations activities carried out to adapt the pilots to process car electronic in an optimized way;
- WP6 is the work package of the industrial demonstration activities, to test the circular digitalized value chain developed with the industrial partners of the consortium.

WP7 to WP10 are grouped under the third layer of "Parallel activities", since they are transversal to the whole project's tasks and duration:

- WP7 manages the dissemination and communication activities;
- WP8 accounts for the exploitation routes and plan, the standardization of TREASURE processes and results, and the identification of business model and related implementation strategies;
- WP9 is related to project management, reporting and monitoring progresses, organizing periodical consortium meetings and handling legal and contractual issues;
- WP10 is a work package added in a DoA updated version to manage ethical requirements.

WPs leaders must take this framework as a reference for leading their activities, since it identifies the main objectives to be achieved considering the timing, the contributors and leaders and the expected contribution to be provided. Indeed, for each work package in the scheme, entering and exiting connections with other work packages has been derived from the DoA. For instance, WP2 takes as inputs the reference framework of T1.1 and the platform and pilot requirement specifications (T1.2, T1.3) to define the sustainability and circularity impact assessment methodology (T2.1) and the sustainability advisory methodology based on data science (T2.2). In turns, these methodologies defined in WP2 will be exploited throughout the project in WP3, WP4, WP5, WP6 and WP10. The interactions will be further investigated in §3.1.3.
An additional layer can be identified and labeled as "Operational activities", as can be seen in the red box of Figure 6. The layer is constituted by WP3, WP4, WP5 and WP6, since these work packages are those deeply related to the development of the tool and of the demonstration activities, thus to the operative tasks of the project. As explained in the following §3.1.3, the focus was set on this layer, and the interactions among work packages and tasks have been deepened only for the work packages and tasks that are part of the operational layer.

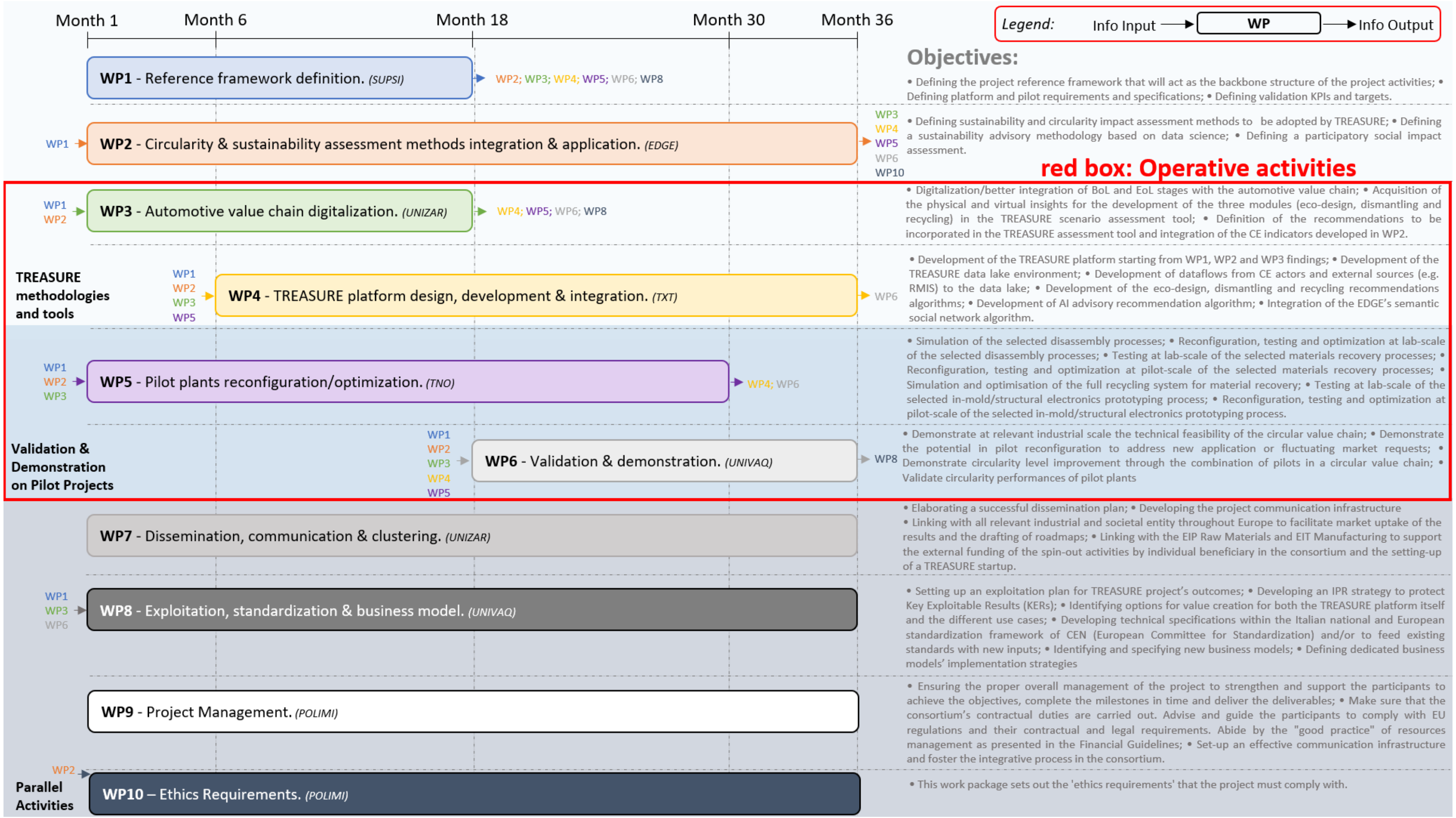

Figure 6. Relationships between WPs and objectives according to the DoA

3.1.3. Logical

In this section, the logical architecture of the project at work packages level has been developed. As mentioned in previous section, the focus has been set only on the operational layer, namely on WP3, WP4, WP5 and WP6. Indeed, these work packages constitute the core of the project, since they involve the activities that will lead to the creation of TREASURE results and give main value added to the project. Moreover, the complexity of the interconnections and data flows to be managed in these work packages required a deepening that is not strictly necessary in other work packages. Actually, WP1 and WP2 provide as inputs the basic references, frameworks and methodologies to the whole project, but they do not require input from other work packages, while the "Parallel activities" work packages involve more straightforward flows of information, which do not justify being further at this stage of the project.

Thus, focusing on the operational work packages WP3, WP4, WP5 and WP6, the connections among work packages in terms of inputs and outputs of materials, services, information, milestone, etc. are investigated. The framework presented in Figure 7 represents the connections between these work packages.

Starting from WP3, it is possible to observe how this WP interacts with WP4 and WP5:

- It interacts with WP4 as it provides to the platform development inputs such as: 1) insights for Eco-design, disassemblability and recyclability modules; 2) Insight for the CE Labels; 3) First data on the most critical components of the three selected vehicles incorporated into the platform in a secure way. In detail, WP3 simulation models will dictate the level of detail for data to be collected/available from car design, based on the tools and the physics of recycling processes (both shredding/sorting and metallurgical recycling processes).
- It provides to WP5 flowsheet simulation tools to compare pilot plant performance (in terms of recovery, losses and exergy) with existing metallurgical recycling processes to define the best suitable and most optimal processing routes for the disassembled automotive parts. In return, WP5 provides the results of disassembly, recycling, and prototyping simulation (such Recycling/recovery rates) at lab scale, thanks to which it is possible to make a comparison with WP3 outputs from dismantling and recyclability assessments.

Proceeding with WP4, it has been observed that WP4 interacts with WP3, WP5 and WP6:

- Interactions with WP3 have already been described;
- Interactions with WP5 include: an LCA analysis for the conventional device that serves as the basis for the In/Mold Structural Electronic (IMSE) device that will eventually be developed in WP6, but prepared in part in WP5; the platform makes available aggregate information indicating the most valuable car parts, disassembly times and tools (useful in WP5 for the FENIX PCB disassembly station @POLIMI's I4.0 Lab reconfiguration & optimization); the tool provides guidance on the best recycling routes and processes for optimal recovery with aggregate data, extensive data on the composition of flexible electronics (compared to traditional alternatives), and comprehensive information on hydro plant flowsheets and output/results that will be used for comparison to required metallurgical routes in WP5. Finally, it provides guidance on substitution of critical raw materials, improvement of recyclability, and retrofitting for InSCOPE pilot line @ TNO's Holst Centre.
- Regarding WP6, there is an iterative process between tool development and use case results. Indeed, the platform is responsible for evaluating the three pilots' new process performances in terms of circularity. In return, WP6 provides the results of metals recovery and process technical-economic feasibility. These results could be used in implementation of the modules.

WP5 also interacts with all other WPs:

- The relationships with WP3 and WP4 have already been described;
- WP6 is strictly connected to WP5 since the reconfiguration of the pilot plants and the processes optimization are preparatory for the demonstration activities in WP6.

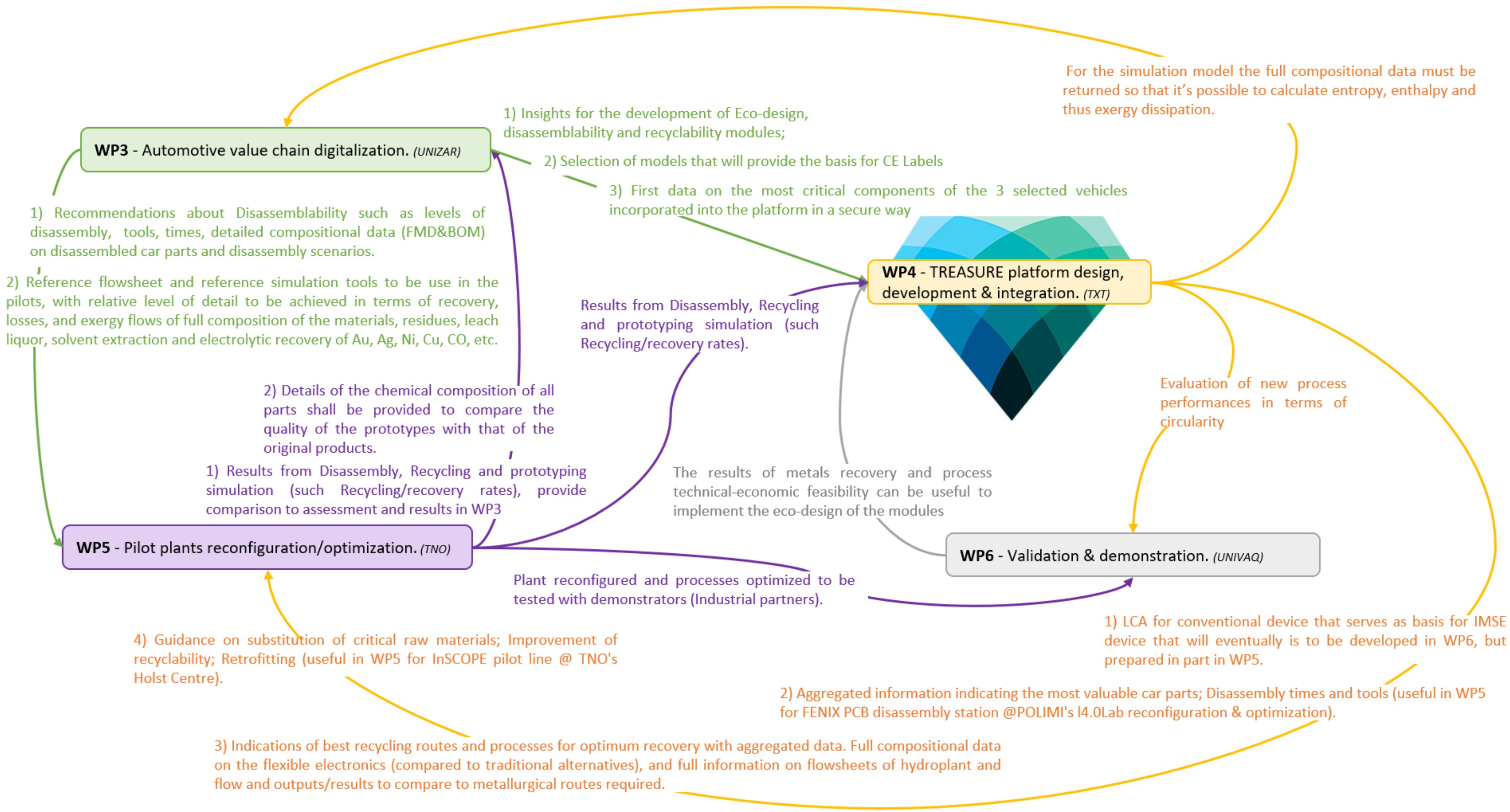

Figure 7 Project framework at the WPs interconnection level

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3.1.4. *Criticalities*

Under the logical interconnections point of view, some criticalities have emerged from the consortium discussions, which can be summarized as follows. The data about full composition of selected components, highlighting the percentage of each element and the design configuration, is a key data flow needed throughout the project development. Indeed, without accurate data related to materials, it will not be possible to achieve reliable results in terms of simulations and sustainability assessment, because it will be not possible to know the amount of material that is actually recoverable from EoL car parts and the amount of material that is consequently reusable as secondary raw material from new electronics prototyping.
Further discussion will be held in the context of WP5 activities, where these detailed data will be shared to enable POLIMI carry out the disassembly and UNIVAQ the recycling of flexible prototypes provided by TNO and of any kind of car electronic component disassembled by POLIMI.
Data sharing availability constitutes one of the main barriers for the actual automotive value chain to its evolution to a more circular dimension, and it is one of the objectives of TREASURE to try to overpass it by filling the gap in information sharing. However, this constitutes a major criticality that will be addresses in T1.2.
A further critical point noted concerns the results obtained in WP5. It is not clear whether these results come back as feedback to WP3 for reworking the assessments, or whether they provide direct input to the platform.

3.2. Task-level

This section concerns the description of the project interconnections at tasks level. The relationships among tasks of operational work packages are investigated, providing an additional picture of the project activities that depicts how the operational sub-tasks contribute to three lifecycle phases on which TREASURE acts to improve circularity performances. The lifecycle lines of disassembly, recovery and eco-design phases and their interactions with the platform are described in §3.2.1, focusing in detail on the ongoing tasks and leaving the reference to Miroboard for the others. In §3.2.2, the Key Enabling Technologies are mapped and described under the same point of view, namely in light of their contribution to the operative tasks. In §3.2.3 instead, the Key Enabling Technologies contributions to circularity of the value chain are identified and the results placed in the context of exploitation analysis.

3.2.1. *Logical interactions*

Beside the interconnections among work packages, analyzed in §3.1.3, an additional level of detail is provided by focusing on the tasks relationships both inside the same work package and among different work packages. Figure 8 shows the activities flowchart, where the tasks and sub-tasks relationships highlighted has been validated by TREASURE partners. Figure 9 shows the same overall picture of the tasks, rearranged to make evident their reference work package.

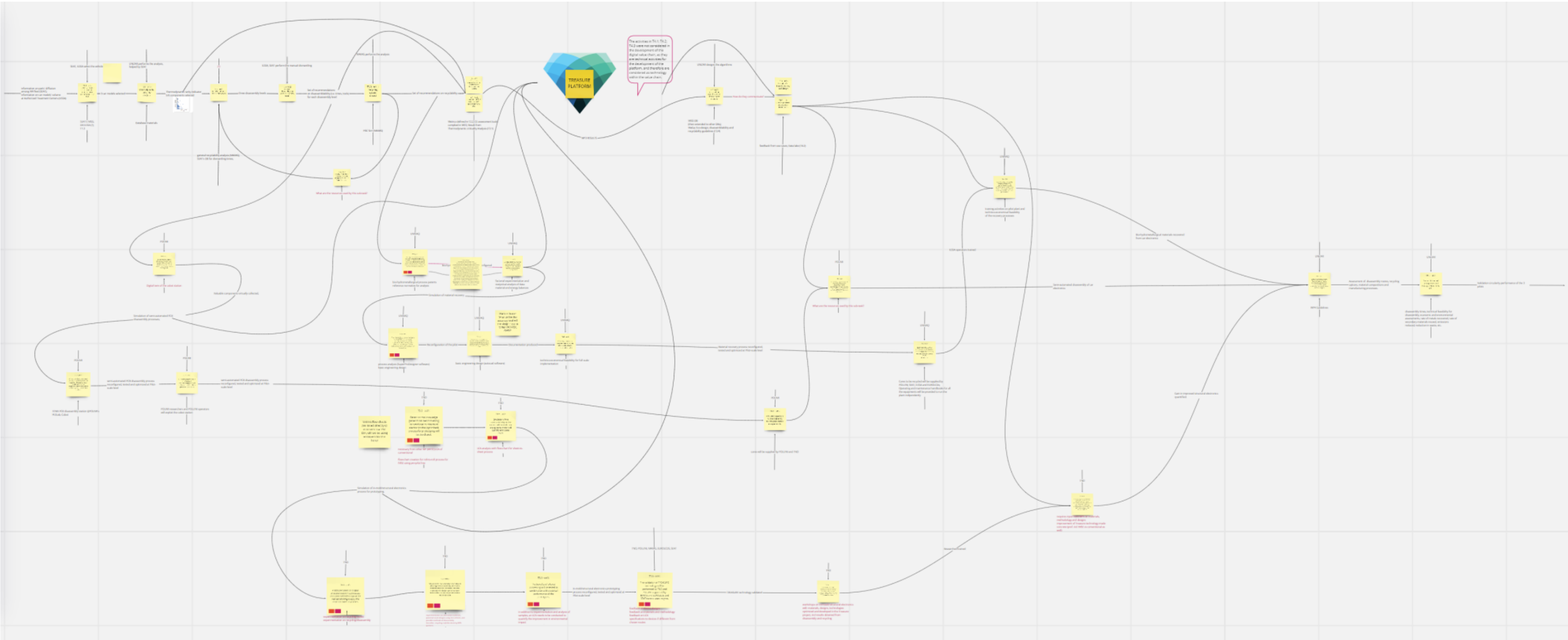

Figure 8. Task level scheme

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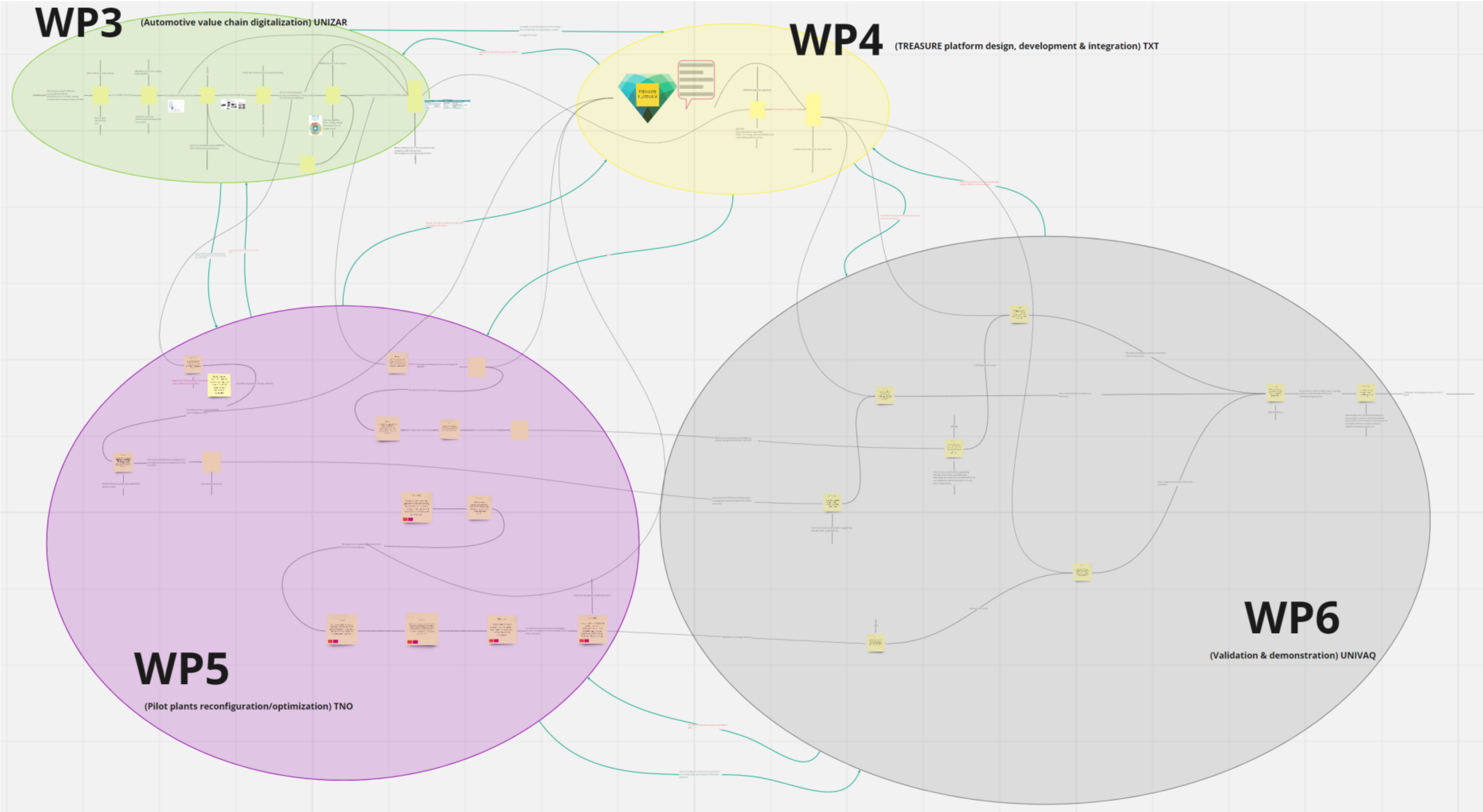

Figure 9. Task level scheme – WPs reference

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Being the number of tasks considerable a selection has been made to show the detailed input and output flows, and point out criticalities in terms of cause and effect's relationships, timing and milestones to be achieved. The first selection fell on the tasks part of operational work packages WP3, WP4, WP5 and WP6, whose interactions at work packages level have been analyzed in §3.1.3.
Starting from the information elaborated to map the activities flowchart in Figure 8, the sub-tasks have been arranged in a new framework not only based on the work package of belonging, but on their final contribution to project results. Indeed, TREASURE focuses on providing circular improvement on the automotive value chain by acting on three specific lifecycle stages, namely eco-design, disassembly and recovery processes and management. Thus, the sub-tasks can be grouped based on the lifecycle phase to which they contribute with the purpose of providing a picture of the project activities in a circular view. The sub-tasks were allocated on the graphical framework of Figure 10, which in divided in three layers and that can be found at the workshop link reported in this chapter for better graphical viewing:

- The upper layer represents the three lifecycle stages of disassembly, recovery and eco-design, and it is populated with the activities of WP3 and WP5 that are propaedeutic to the development of the lower layers;
- The middle layer is the platform one, where all the sub-tasks of WP4 are inserted;
- The lower layer is the use cases layers, where all the sub-tasks of WP4 are placed.

This characterization of the sub-tasks allows:

- Transversal channels along which the information must flow within the project, which are the disassembly-aimed, recovery-aimed and eco-design-aimed activities lines;
- Mapping the sub-tasks that serve as a bridge from one layer and the other, and from one line to another;
- Pointing out the central role of the platform, which is the software enabler of the shift from analysis, reconfiguration and simulation activities of upper layer to the development of the new ELVs management processes in the industrial reality within the consortium;

Making an example, all the activities related to disassembly assessment and data gathering (i.e., T3.1, T3.2), dedicated pilot reconfiguration and simulation (i.e., T5.1, T5.2) were grouped under the disassembly-labeled area. Pilot 1, which is shown with the same green color, is the counterpart for the disassembly area, because it is the industrial case involved in the validation of new disassembly routines. The same reasoning applies to the recycling and eco-design phases, identifying also the sub-tasks that link areas between them (e.g., T3.3 from recycling area of interest provides inputs to disassembly area). The scheme aims at pointing out also visually the central role of the platform, which is receiving data from tasks to develop its modules architecture (see the T3.4 exchanging between upper and middle layer) and exchanging information with the industrial pilot case (interconnections sub-tasks in between middle and lower layer), with the double scope of validating its structure and optimize the circular value chain processes.
In this framework, it is possible to place the Key Enabling Technologies in the pilot layer. KETs in a first moment act independently on the three lifecycle stages lines, because one KET is applied for each pilot and one for the platform but allows a mutual improvement for the transition towards a more circular value chain. In the following §3.2.2 their role in the tasks' activities, and generally, in the project purposes are described.

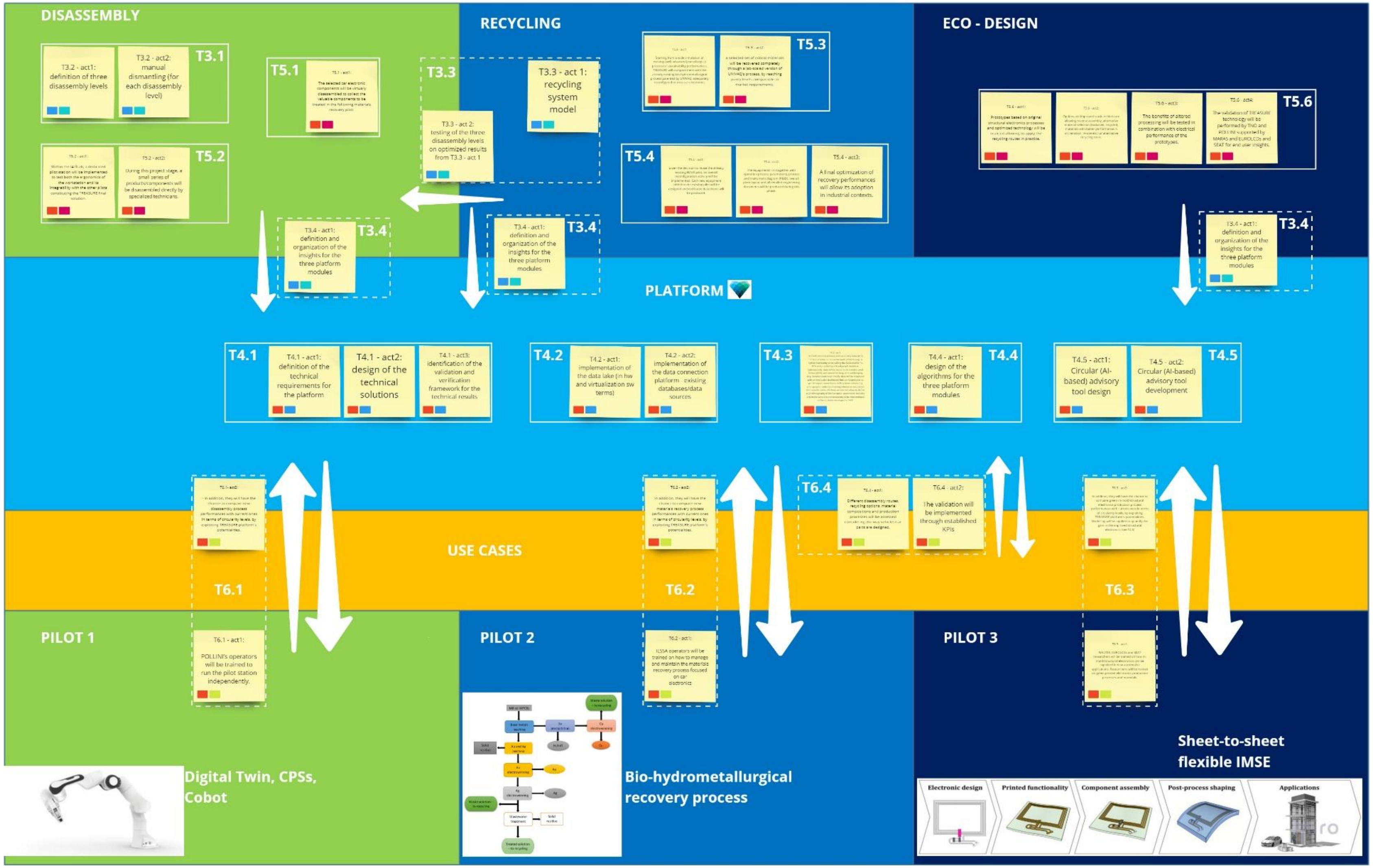

Figure 10. Framework of tasks' intended use rearrangement

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Among the 20 tasks of the selected work packages, the focus was set on the ones already started, namely T3.1, T5.3 and T5.5, being the ones more urgent, plus T3.2, which represents a task from the disassembly area.
The first task analyzed is T3.1, which is the basic step to start the project, because it is the activity aimed at selecting the car models from SEAT fleet in a clever way. Indeed, the criteria of selection of the vehicles is to choose the ones whose components are shared among the greater number of car models. Once the cars are identified, next step is to choose the electronic components accordingly to their thermodynamic rarity indicator, namely according to the exergy cost of their production from the extraction to the EoL. The analysis is performed by UNIZAR with the collaboration of SEAT that provides data. T3.1 graphical representation is shown in Figure 11.

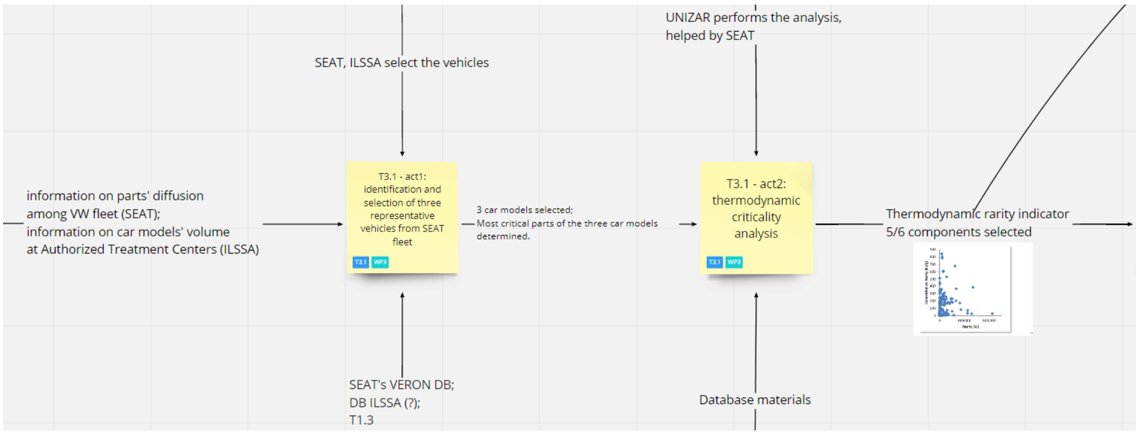

Figure 11. T3.1 graphical layout

Browsing the tasks along the line of disassembly, first activities are part of WP3 and constitutes T3.2. They consist in defining a number of disassembly levels to be tested, which now is set at three, for the car components selected by SEAT in T3.1, and to perform the manual dismantling of these components. The objective of the task is to develop a set of recommendations on disassemblability that will be organized in T3.4, deployed by the platform disassembly module in WP4 and standardized in WP8. Following the diagram referenced in Figure 12, the identified input streams are:

- The thermodynamic rarity analysis indicator performed in previous task T3.1;
- The first trial disassembly levels for each component selected.

The resources exploited in the activities of T3.2 are the general recyclability analysis performed by MARAS through their software HSC. The information coming from private VERON database from SEAT on dismantling times will be merged with the results of MARAS simulations to define iteratively the disassembly levels for each of the components selected by SEAT and UNIZAR in T3.1
The manual dismantling for each level of disassembly is performed by ILSSA with the help of SEAT and UNIZAR and information about tools and times are recorded to create a set of recommendations to be provide to the platform modules.

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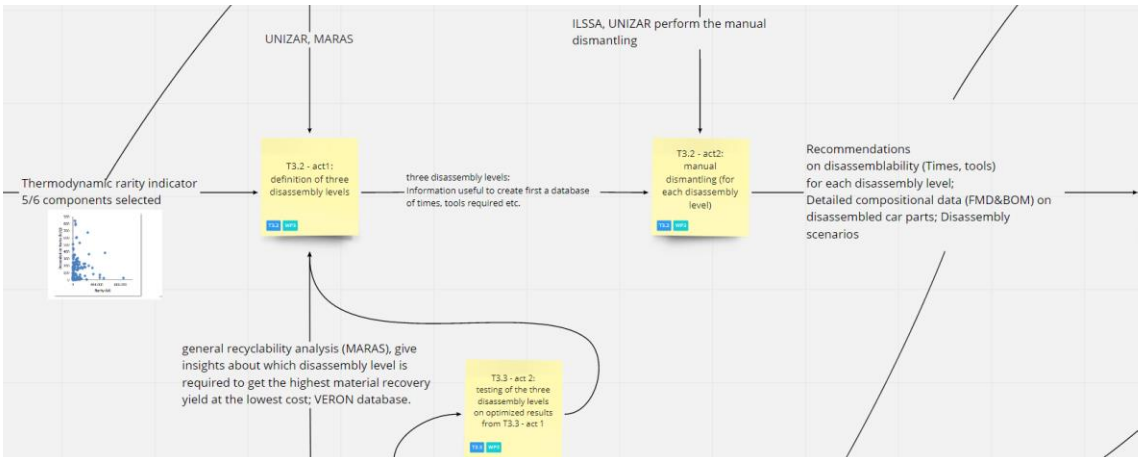

Figure 12. T3.2 graphical layout

Repeating the reasoning for recycling, the task described is the T5.3, which is splitted in two sub-activities, as can be seen in Figure 13. Both the activities are led by UNIVAQ in their pilot plant. The first activity is to compare their patented process with other well know processes in terms of sustainability performance, after having reconfigured the plant to treat car electronics. The bio-hydrometallurgical process reconfiguration refers to both UNIVAQ's patent and reference normative for the analysis, and needs as inputs the set of recommendation on recyclability coming from T3.3 analysis. After the reconfiguration, the second activity is the lab-scale version of critical materials recovery process performed to simulate the actual one. UNIVAQ will exploit factorial experiment design and statistical analysis of material data and energy balance to set up the simulation and provide as output hints for the industrial validation. As remarked by MARAS, the completeness of data flowsheets is fundamental to get reliable results and link activities on recovery with analysis of material recoverability rate and thermodynamic rarity indicator. In particular, it is of key interest to map the leach residue composition and quantity both to assess the actual circularity of material and to provide further information on the economical side to optimize the whole value chain processes.

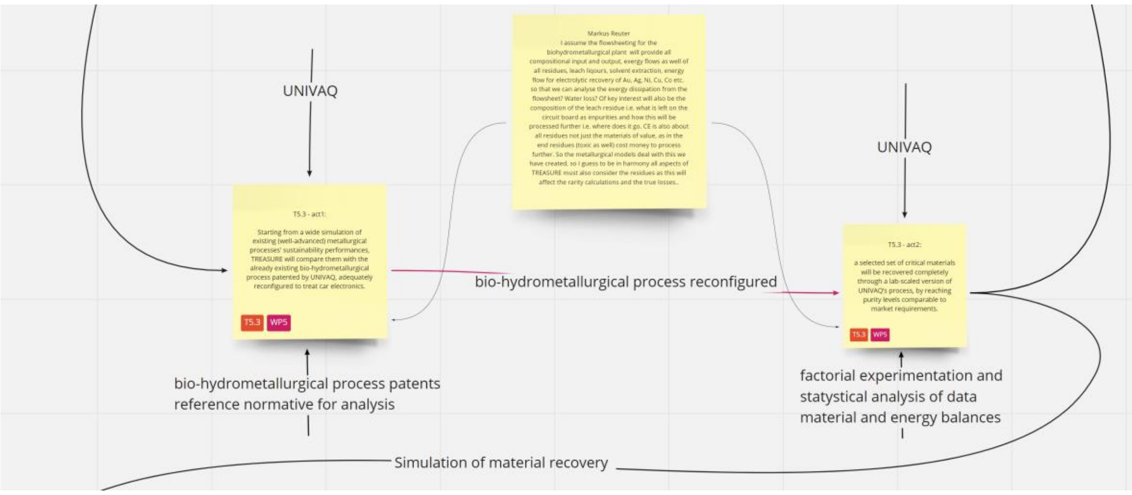

Figure 13. T5.3 graphical layout

Along the line of eco-design, T5.5 is considered, whose leader is TNO as expert of IMSE production process. Referring to Figure 14, first activity consists in analyzing benchmarked results between traditional and structural electronic prototyping to developed and optimize the new roll-to-roll process. The parameters on which the comparison is performed are the flow chart of the new roll-to-roll process in the pre-pilot line and LCA assessment results, whose criticality relies again on the level of detail of material data, as seen in §3.1.4. The LCA

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assessment will be performed by TNO in collaboration with MARAS and SUPSI. The simulation of the process will be performed according to the LCA analysis for sheet-to-sheet flow chart as reference, and provide the basis for the industrial pilot case.

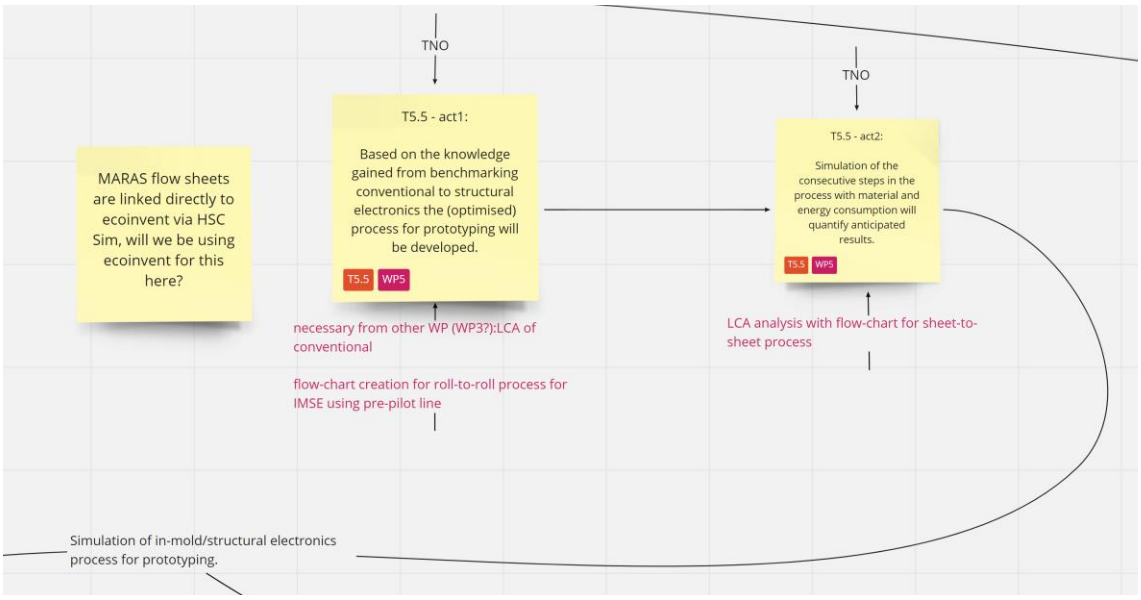

Figure 14. T5.5 graphical layout

For all the tasks that are not mentioned in this chapter, it is possible to refer directly to the Miroboard, available at the following link:
https://miro.com/app/board/o9J_l6k982c=/?utm_source=notification&utm_medium=email&utm_campaign=daily-updates&utm_content=go-to-board
where it is also possible to have a better understanding of schemes presented in Figure 8, Figure 9 and Figure 10. The board is not public: it requires permissions to be accessed by the owners (i.e., by SUPSI), thus, the information contained in it is accessible only for authorized users (i.e., for the TREASURE consortium).

3.2.2. Key Enabling Technologies on the sub-tasks framework

In this section, KETs are mapped on the framework of Figure 10. Indeed, the impact of the KETs on the enhancement of the circularity of automotive value chain will be evaluated and tested in the use cases tasks. Each use case is developed in a laboratory pilot plant, properly reconfigured to meet the requirements of TREASURE operational context (in WP5), and then test in real industrial context (in WP6).
The scheme in Figure 15 represents the links among the different technologies and the use cases in which they are exploited. Each use case tests one of the KETs, thus the KETs can be mapped in the framework of Figure 10 as part of the disassembly, recovery, eco-design lines separately. A special case is the one of AI, which is adopted in the development of the Circular Advisory tool of the platform.

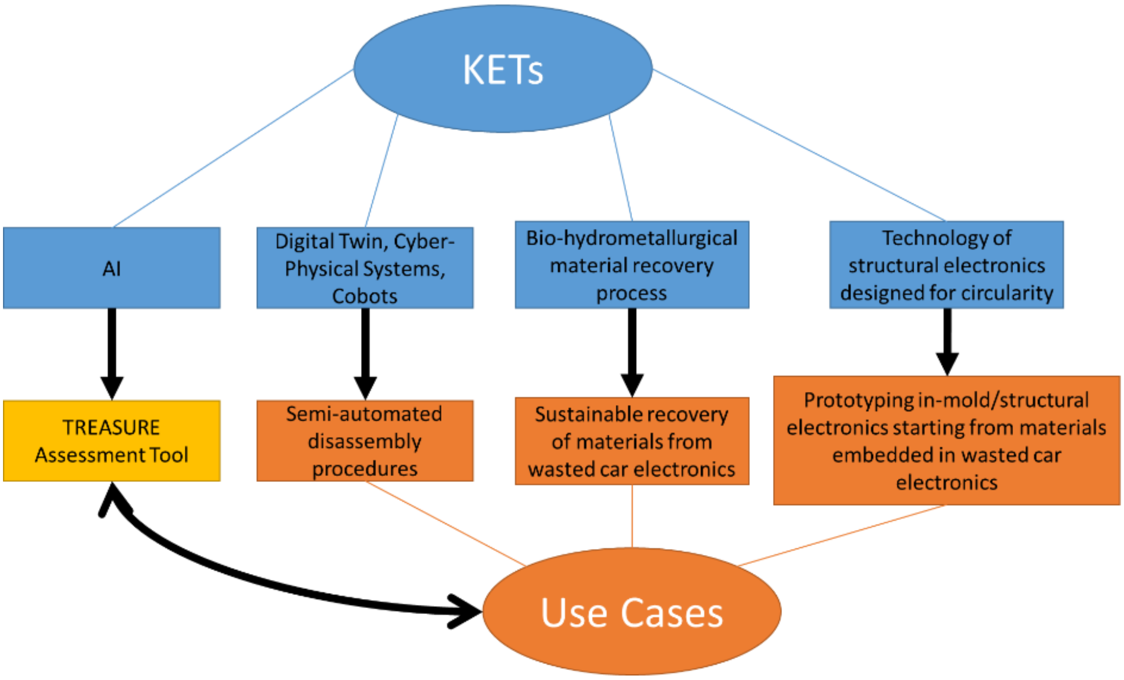

Figure 15 Key Enabling Technologies exploitation in the Use cases

The **first KET** to be assessed is the Cyber-Physical Systems (CPSs), Digital Twins (DTs) and cobots application to car parts disassembly processes. The evaluation is developed in the context of T5.1, T5.2, and T6.1 at the FENIX PCB disassembly station at POLIMI's I4.0Lab. The pilot plant will be reconfigured for managing obsolete car electronics: a dedicated disassembly cell will be created within the lab (T5.1). In this cell, CPSs and DTs will be adopted to run simulations, and then both manual and cobot-assisted disassembly processes will be tested in practice (T5.2). The adoption of these technologies at EoL disassembly stage will allow the development of semi-automated disassembly procedures of high-value car electronics components (T6.1).
The **second KET** evaluated is the bio-hydrometallurgical material recovery processes to recover valuable/critical raw materials from wasted car electronics. The assessment is developed in the activities of T5.3, T5.4 and T6.2 at FENIX pilot plant at UNIVAQ. The plant will be reconfigured to manage materials embedded in wasted car electronics in a sustainable way, by rethinking of both biological acids and reagents to be adopted in the recovery of materials (T5.3). In a lab-scale version, the car electronics waste, previously disassembled to recover hazardous components, will be reduced into powders, separating in metal and non-metal ones, and finally only precious metals (e.g. Au, Ag, Pt, Ta) will be refined completely through bio-hydrometallurgical processes (T5.4). The process will be then run at industrial level in T6.2.
The **third KET** evaluated is the In-Mold Structural Electronics (IMSE) adoption to design structural electronic parts from materials embedded in wasted car electronics. The evaluation will be carried out in T5.5, T5.6 and T6.3 at InSCOPE pilot line at TNO's Holst Centre, which produces structural electronics part by printing, assembly of components and finishing by lamination and thermoforming. The advantages in technological terms of this relatively new (film-based) printed electronics technology over conventional electronics are well known, while the sustainability performance have not been investigated yet. Thus, a car electronic component designed from either conventional or printed flexible electronics will be benchmarked. Basing on the outcomes of the benchmark in terms of material usage, stack architecture, processing phases and recycling options/routes, an optimization of the flexible printed electronics production process will be implemented (T5.5). TNO's pilot line will be reconfigured for managing green materials, namely to reuse secondary raw materials from e-wastes, during the production of flexible printed electronics in case this is identified as most valuable option for improved circularity (T5.6). The industrial test will be performed in T6.3.

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The **fourth KET** evaluation concerns the adoption of AI in T4.4 and T5.5 for the design and implementation of the Circular Advisory tool. AI will allow both an optimization of product design and development practices, and an optimization of operational procedures at EoL stages. Indeed, based on a real-time sharing of information within the automotive value chain the integration of assessment modules will be enabled in such a way that these modules can provide guidelines to support users.

3.2.3. Key Enabling Technologies and circularity framework

The interconnection flows, described in previous sections, have been investigated with the aim not only of sharing the project's architecture but also of highlighting the means TREASURE activities will exploit to act on the transition of the automotive value chain towards a new, more circular dimension. In this section, the role Key Enabling Technologies plays in this transition is pointed out, in terms of improved sustainability performance, output quality level and technological development of ELVs management practices. This allow to depict the circularity framework, describing how TREASURE demonstrators can enhance best circularity practices in automotive value chain, opening the discussion on results exploitation and placement along the current and future mobility of chapter 4.

Even if the exploitation and validation of the KETs run separately on the three pilot plants and on the Advisory Tool, the improvements introduced by their application under the sustainability and circularity points of view will link the considered lifecycle stages by increasing their performance reciprocally. Indeed, starting from use case 1, the improvements introduced by the application of KETs in the disassembly stage results in the optimization of car electronics' disassembly procedures, which leads to greater availability of components that could be either reused as secondary spare parts or recycled. In the second case, KETs application to disassembly processes allows a higher efficiency of subsequent materials recovery stage. This, in turns, together with the bio-hydrometallurgical recovery process optimized for the automotive electronic car parts, allows the circulation of secondary raw materials obtained from electronic wastes. Thus, besides the reduction of hazardous wastes and of natural resources depletion, the KETs applied to recovery process will provide circular materials by closing the loop on eco-design phase. Indeed, material recovered will be directly used as basic material in both traditional and innovative car electronics production processes. In case of innovative design, the prototypes produced with IMSE will be optimized to meet circularity insights from recovery processes simulations. In the same way, the recovery and the disassembly stages influence each other in order to optimize the EoL stages. The optimization procedures pass through the simulations iterations on levels of disassembly and materials recovery rates.

Figure 16 reports schematically what has been described: the use cases in the blue circles are defined by the lifecycle stages to which they belong, the KETs applied, the pilot plants in which they are performed and the modules to which they contribute. In the context of the project, the results of demonstrations and KETs applications will be deployed to create the modules of the TREASURE platform, but outside the project, they will be exploited as guideline for the transition to circular practices in automotive value chain.

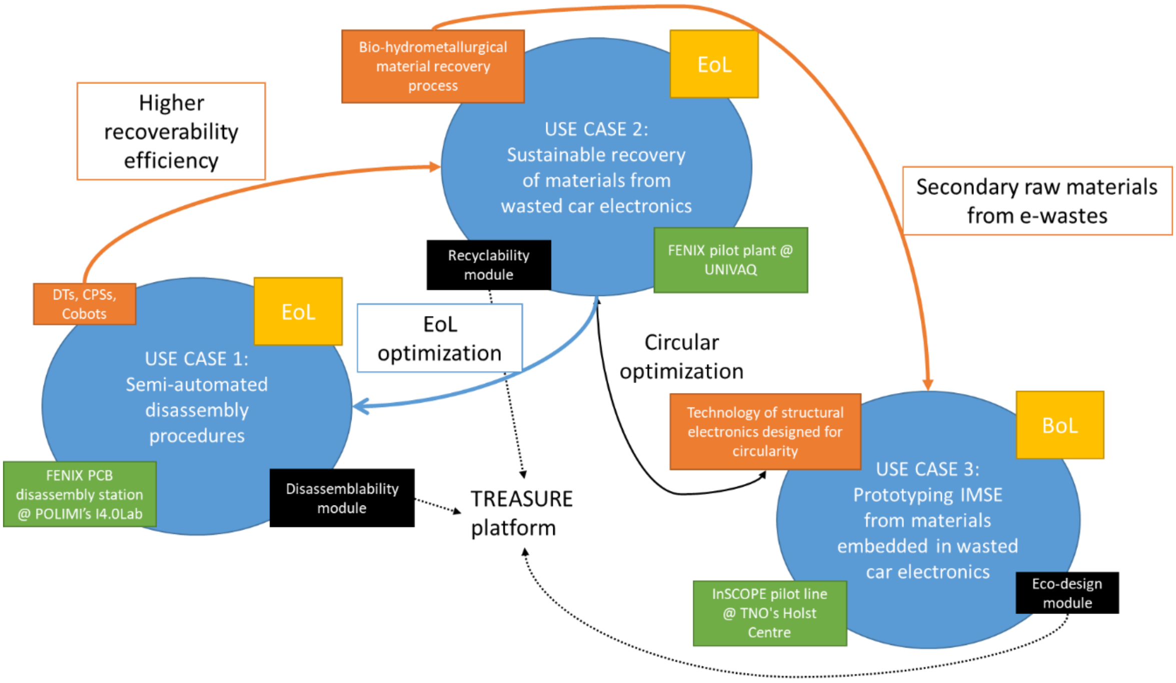

Figure 16. Picture of the use cases demonstration for the exploitation

To close the circularity framework, it was desired to identify which is the contribution of KETs presented in Figure 16 for the automotive sector. Therefore, it was intended to map, not only the contribution of KETs within the project, but also outside the project. This analysis is presented in Chapter 4 and covers the levels of circularity, the circular business models, and the enablers/solutions affected and identified by the SoA.

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4. Circular trends in the automotive industry related to the project

This chapter is dedicated both to close the discussion on the circular framework at the project level and to cover the TREASURE vs CE in automotive level. The content and purpose of the sections in this chapter is distributed as follows: §4.1 describe the circular cars initiative (CCI), and the related reports contained therein and why it was chosen as the SoA's primary reference. §4.2 indicates which areas of research and innovation highlighted in the trends of §4.1 are addressed by TREASURE, deals with closing the circular design framework initialized in §3.2.3, covers the reference framework "TREASURE vs CE in automotive level", and provide useful input to WP8 in the activities related to the identification of the business models.
The value of a circular economy lies in its ability to conserve raw materials while eliminating waste as much as possible. COVID-19, which hit economies hard and put pressure on resources, has made us even more alert to the risks attached to global supply chains. 51% of supply chain professionals expect an increased focus on the circular economy in the next 2 years. Industries with greater financial resources and risk propensity are the most optimistic about the growth of this new economy. For the automotive industry this transformation can be compared to Henry Ford's assembly line, or Toyota's Just in Time. In fact, it impacts the way the value chain was previously designed. By 2050, global passenger demand is expected to double; with current business models, this fact results in greater resource pressures than today. Automotive electronics are one of the most valuable sources of critical raw materials (CRMs) in automobiles, however it is not being recovered properly. TREASURE will support the End-of-Life (EoL) and beginning of life (BoL) phases of vehicles by providing an AI-based scenario assessment tool and by Integrating the key enabling technologies (KETs) for the efficient design of automotive electronics and subsequent disassembly and material recovery to dismantlers, shredders, recyclers, and manufacturers. TREASURE can provide a good opportunity to test innovative technologies to make the automotive sector more circular by moving beyond some of historical limitations that characterize this industry, such as the disconnect between BoL and EoL due to communication shortages between automakers/automotive parts suppliers, and dismantlers / shredders / recyclers.

4.1. The Circular Cars Initiative (CCI)

This chapter summarizes the major trends identified by the Circular Cars Initiative (CCI). The CCI is a global initiative that help to accelerate collaborative actions in the automotive value chain[3]. Within CCI there are between 40 automotive value chain companies, various research institutions, international organizations, government agencies and think tanks. This initiative aims to achieve net-zero carbon emissions in the whole automotive lifecycle and increase material efficiency and vehicle utilization. The initiative settled an agenda for the transition of the automotive industry towards circularity through creating collective knowledge, proof of concepts and policy discussions. It was chosen to use the CCI as the SoA reference because it is a global reference for decarbonization and supply chain digitization, they have a holistic approach to mobility, and they have defined the taxonomy. Since December 2020, 4 reports have been published that dictate the guidelines for industry transformation. In D1.1 the second report "*Raising Ambitions: A new roadmap for the circular automotive economy*", has been mainly taken as reference. In subchapters §4.1.1, §4.1.2, §4.1.3, and §4.1.4 an overview of the 4 reports is provided. In the subsequent phases of TREASURE, those relating to recycling

[3] https://www.weforum.org/projects/the-circular-cars-initiative

simulations, it is advisable to use the third "*Forging Ahead: A materials roadmap for the 'zero-carbon' car*" report as a reference, as in it are the cost and emission forecasts for the different materials contained in a vehicle. One of the goals of Chapter §4 is to align TREASURE's circularity goals with those proposed by the CCI and to identify areas of research and development that can benefit from the activities explored in TREASURE

4.1.1. The Road Ahead: A policy research agenda for automotive circularity

The first report, "The Road Ahead: A policy research agenda for automotive circularity,"[4] was produced by the World Economic Forum with input from World Business Council for Sustainable Development (WBCSD) and Systemic and released in December 2020. This work addresses how today's policy and regulatory frameworks support high-level circularity, and calls for faster electrification of vehicles, adoption of low-carbon technologies, subsidies for end-of-life management, and ultimately incentives that will support industry transformation. Considering the trend of carbon emissions per passenger km in the various phases that the car revolution will go through in the coming years, it can be found that at first, electric cars will be adopted favoring a decrease in emissions of 15%. The next big decrease in emissions will take place on the energy front: the transition to renewable energies will allow a further decrease in emissions of 64.5%. It is at this point that implementing the principles of circular economy, in the most optimistic forecasts, will allow a further decrease of 93%, resulting in an overall decrease of carbon emissions per passenger km of 98% compared to today. For emissions strictly related to materials, trends show an increase between 150% and 200% between internal combustion engine vehicles (ICEV), and battery electric vehicles (BEV). This increase is mainly due to the production of batteries that are highly energy intensive in their production.

4.1.2. Raising Ambitions: A new roadmap for the circular automotive economy

The second report, released in December 2020 and published by Accenture strategy, is entitled "Raising Ambitions: A new roadmap for the circular automotive economy"[5]. It proposes a framework for increasing both materials and use-phase efficiency in the automotive sector. This report examines innovative approaches to emerging business models to enable high-quality recycling and second-life battery use. The aim of this report is to lay a foundation for future discourse on automotive circularity by providing a framework for understanding circularity within the automobility ecosystem. Achieving circularity is a complex endeavour. To clarify the path forward, this study lays out a five-level taxonomy for circularity (0 = no circularity, 5 = net positive impact). This report also identifies business models that will generate more mobility and less waste in the future. Based on current technology, there are opportunities to reduce carbon emissions up to 75% and resource consumption up to 80% per passenger kilometre by 2030. There are levels of circularity identified by the CCI ranging from level 0 to level 5. They indicate different goals, past, present, and future of circularity. Vehicles industrial sector is currently at level 1 while in the past it was at level 0. Circularity Level 1 is the current level and is characterized by a sales-optimized value chain. It focuses on cost reduction and there is no coordination between actors along the value chain. An example of the actions belonging to circularity level 1 is the reduction of material waste in production. At level 2, there is an improvement for use-phase emissions and a reduction in resource consumption. At this level, the value chain will be more interconnected and coordinated, thus ensuring a longer life and improvement in the use phase. Significant portions of our automotive system will likely reach level 2 circularity by 2025. At Level 3, the entire vehicle lifecycle is optimized. At this level the

[4] CCI, "The Road Ahead: A policy research agenda for automotive circularity" (2020).
[5] CCI, "Raising Ambitions: A new roadmap for the circular automotive economy" (2020).

shift to car-as-a-service and fleet solutions supports this optimization and incentives are aligned all over the value chain. It should begin to feature large portions of the mobility system by 2030. At level 4, the value chain is completely circular and waste free. At this level, carbon emissions are 0 as the consumption of non-circular resources. Achieving level 4 circularity requires a transformation of the value chain, market structure, and vehicle. This type of transformation could be found in the automobile by 2035-2040. Some elements of Level 4 circularity have already been experimented by some companies and research organisations. One challenge is to achieve scale and making a new value chain to sustain Level 4 circularity. With appropriate political support, Level 4 circular cars could begin to emerge in the next few years. Level 5 circularity is an aspirational vision. Despite this, elements of it are already being tested and even in use today, as this level can be developed in parallel with levels 2-4 and lower levels of circularity should not be seen as necessary intermediate steps. Cars will help make system-wide improvements across modes, upgrading materials, and improving energy networks. The entire system will then be highly integrated, optimized, and sustainable. Integration and alignment with neighbouring ecosystems and convergence of business models and services will be a crucial part. An example already in use today are electric vehicles already being used to balance the grid and absorb renewable energy that would otherwise be wasted. Inspired industry leadership and supportive policy, smart business models, and the ingenuity of automotive engineers are needed to achieve a level 5 circularity. Circularity within levels is broken down in terms of energy, materials, lifetime, and use**.** The Accenture Strategy analysis[6] allocated high-level solutions on the different level of circularity based on their positioning in terms of usage transition and product transformation. Table 2 shows the description of each solution, while Table 3 shows the enablers that will support the solutions to come to fruition. It is possible to observe that the solutions that see a greater transformation of product are “Energy grid integration”, of level 5; “Circular material stock” of level 4; and “Low-carbon materials” from level 3. The solutions that have the greatest impact on the use phase are “Purpose-built vehicle” of level 4; “Energy grid integration” of level 5; and “Mobility on demand” of level 3.

Table 2 Description of most promising solutions for circularity and relative level of circularity

Solution	Impact description	Level
Low-carbon materials	This solution involves recyclers and material suppliers taking energy efficiency measures and increasing the use of renewable energy in the recycling of automotive materials. New technologies are used to decarbonize energy-intensive processes in the production of virgin materials where they cannot be replaced by recycled materials. In this way, CO_2 from materials can be reduced. This solution will remove the CO_2 that is not abated by the "circular material stock" solution, filling the gap.	3
Low-carbon production	This solution considers energy efficiency, and renewable energy use measures charged to OEMs and component suppliers in component manufacturing and vehicle assembly. The solution focuses on decarbonizing energy use in component manufacturing and assembly. CO_2 emissions from both manufacturing and assembly that are generated by the current energy mix are removed.	2

[6] CCI, “Raising Ambitions: A new roadmap for the circular automotive economy” (2020).

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Minimized production scrap	In this solution OEMs and component suppliers collaborate with material suppliers to reduce material waste in production. New processes are developed to optimize recycling rates and quality of inevitable production waste. Reducing production waste reduces CO_2 emissions from materials. Improved recycling of production waste reduces the amount of non-circulating waste per car.	2
Modular vehicle design	By integrating the knowledge of repair and recycling experts with that of OEMs and component suppliers in the product development process, new cars are designed using modularity. Disassembly and remanufacturing will be simplified by allowing the circular principles of refurbishment, component upgrades and scope adjustments to be implemented as economically feasible. Improvements will include those related to the use phase, measured in life cycle kilometers. It should be kept in mind that with this solution, total material use and CO_2 from material increase a bit due to the higher number of spare parts used over the life cycle.	3
End-of-life management	This solution improves the processes of disassembly, sorting, reverse logistics, and maximizing value recovery. OEMs, suppliers, and recyclers work together to increase the efficiency of these processes. Components and materials are funneled to remanufacturing facilities, and recycling facilities. This solution increases the circularity of end-of-life vehicle outflows. Non-circular car outflows are reduced, resulting in less CO_2 from end-of-life treatment.	3
Circular material stock	100% recyclable materials form a fixed size stockpile ("same value loop recycling"), which is used and reused. With this solution, waste and downcycling are reduced, and materials are recycled at the highest level by specialized recyclers. Circular inventories must be established for selected materials (e.g., aluminum). Business models such as Materials-as-a-service allow closed-loop recycling of selected materials. Non-circular auto inflows and outflows are eliminated. CO_2 from materials is greatly reduced to lower the carbon intensity of recycled materials. CO_2 from end-of-life treatment is reduced.	4
Component-as-a-service	This solution calls for critical components with higher value to be sold as a service. Batteries are an example of a high-value component with the potential for extended life in automotive and non-automotive applications and closed-loop recycling at the end of life. The most realistic scenario involves business-to-business (B2B) models, where the manufacturer provides the critical components to the OEM in a full-service model. The OEM in turn, sells the car including the critical components to the consumer, and provides the warranty for the service. Another scenario is where the OEM sells the cars without critical components, allowing aftermarket suppliers to supply and manage inventory. The solution is modeled with battery-as-a-service as the primary example. The non-circular car inflows and non-circular car outflows are decreased respectively. CO_2 from materials is reduced to lower the carbon intensity of battery materials. CO_2 from end-of-life treatment is reduced.	3
Reuse and remanufacturing at scale	OEMs, component suppliers (original equipment and independent aftermarket) and workshops push for a vibrant reuse and remanufacturing market. Necessary technologies are improved, processes automated, and large-scale facilities established to increase cost-competitiveness. Reused, remanufactured, or retreaded components are the default option in the	3

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	aftermarket. Remanufactured components are introduced in new car production. This solution focuses on scaling remanufactured inflows and outflows. As reman shares of inflows and outflows increase, non-circular car inflows and non-circular car outflows are reduced respectively. CO_2 from materials is reduced due to lower carbon intensity of reman components.	
Workshops as a circularity hub	Workshops (intended as mechanical garage), take a central role in optimizing the life cycle of cars and components. Workshops increase cost efficiency, optimize maintenance services based on predictive analytics and use remanufactured parts as the default option. This solution models the positive impacts workshops can have on noncircular resource consumption and lifecycle carbon emissions. It is assumed that optimized maintenance enables longer lifetime of vehicles (measured in life-cycle km). The increased use of remanufactured components instead of new components reduces non-circular car inflows and reduces CO_2 from materials due to lower carbon intensity of remanufactured components.	2
Purpose-built vehicle	OEMs provide purpose-built/purpose adjusted vehicles to mobility providers that enable improved capacity use and optimized vehicle lifetime. OEMs assess use phase requirements and use insights to provide vehicle variations that better align vehicles with their purpose, especially in terms of size, repairability and durability. As seat capacity usage rates for vehicles today are low, the average purpose-built vehicle is assumed to be considerably smaller than the average vehicles today. This can lead to a reduction of total materials in the car and a respective reduction of CO_2 from materials, CO_2 from component production and assembly and CO_2 from end-of-life treatment.	4
Alternative drivetrain	OEMs are scaling alternative transmission solutions with substantially lower emissions. This solution will reduce in-use emissions. Transmission optimization considers the whole vehicle fleet on the roads and the available supply of green energy (e.g., renewable electricity, green H_2). The impact is modeled based on a battery electric vehicle (BEV). Emissions from power generation likely increase depending on the energy mix of the local grid. CO_2 emissions from materials, component manufacturing and assembly, and end-of-life treatment are assumed to increase due to the increased burden of battery manufacturing.	2
Energy grid integration	This solution includes smart charging and vehicle-to-grid (V2G) technology for battery electric vehicles, plug-in hybrids, and fuel cell electric vehicles. OEMs are scaling these solutions resulting in lower emissions generated by electric mobility (well-to-tank) and balancing loads in the energy grid. Fleet management organizations (mobility and financial services) are using this integration for their fleets. It is hypothesized that due to the optimal integration of the car and the energy grid, cars are charged when renewable energy are available, reducing CO_2 emissions from power generation.	5
Leasing and subscription	This solution covers private mobility offerings and concerns OEMs and fleet management companies. Major models include lifetime leasing and subscription-based ownership. The automotive market will transform at scale by favoring as-a-service models. This solution models the positive impacts that garages can have on non-circular resource consumption and lifecycle carbon emissions. The assumption is that optimized maintenance will enable longer vehicle life (measured in lifecycle km). Increased use of	2

	remanufactured components instead of new components reduces non-circular car inflow and reduces CO_2 from materials due to the lower carbon intensity of remanufactured components.	
Vehicle on demand	This solution concerns mobility service providers, who by increasing the usage capacity of vehicles offer on-demand vehicles to customers. These on-demand models include car rental, car sharing, P2P sharing, and micro mobility. Consolidating these holistic on-demand vehicle offerings will allow these models to scale. This solution focuses on fleets of vehicles shared by a variety of users for short periods of time. The shared vehicle is assumed to be treated more carelessly but will receive better maintenance, repair, and refurbishment than a privately owned vehicle. Capacity utilization (average km/year) is increased. Overall, an increase in durability (measured in lifecycle km) can be achieved.	2
Mobility on demand	In this solution, mobility providers increase capacity utilization through on-demand mobility solutions. There are already such business models in the market today, just think of ride hailing, ride sharing, and demand-sensitive transportation/ride pooling. Ride pooling has the potential to maximize the use of vehicle capacity through higher lifecycle kilometers per vehicle and the number of average occupants. This is a solution that focuses on vehicles used by drivers in mobility-as-a-service operations. Maintenance, repair, and refurbishment are assumed to be optimized when compared to a privately owned vehicle. Capacity usage (average km/year) is increased. Overall, an increase in life expectancy (measured in life cycle km) can be obtained. In addition, the average number of passengers can be increased.	3
Breathing fleets	Fleet management companies boost the capacity usage of their fleets by pooling fleet usage among multiple service offerings. Based on the demand cycles (e.g., weekends or business days) and age/quality requirements, cars are moved from one service offering to a different one, resulting in higher capacity utilization for each car over its lifecycle. This solution targets optimized management of car fleet utilization. Capacity utilization (average km/year) is also increased, compared to the split usage of vehicle-on-demand and mobility-on-demand solutions. Overall, an increase in lifespan (measured in lifecycle km) can be expected.	2

Table 3 Enablers that will support the solutions

Enabler	Description	Supported solution
Recoverable and recyclable materials	OEMs, parts suppliers, and material suppliers all cooperate and combine their knowledge about the vehicle design process to improve the recoverability and recyclability of materials. Variability and complexity of the material mix in a car will be adapted to recycling processing options to maximize the recoverability and minimize the creation of residues based on detailed know-how of recycling technologies and requirements of input quality, and new innovative materials are developed.	– Circular material stock – Component-as-a service (e.g., battery)
Product passport	OEMs, parts suppliers, and material suppliers all cooperate in the development and implementation of a vehicle and/or component and material product passport. Significant	– Circular material stock

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	information (e.g., source, material composition) is reported to be shared to optimize re-use, improve the recycling rate and quality, and to allow improved traceability.	– Component-as-aservice (e.g. battery) – Optimized component reuse and remanufacturing – Professional EOL collection, sorting and reverse logistics
Advanced recycling technology and infrastructure	R&D organizations, chemical companies, and recyclers develop innovative technologies to increase recycling and quality rates of materials recycled from end-of-life vehicles. OEMs, and material suppliers integrate their knowledge, expand their co-founding options, and support pilot projects.	– Circular material stock – Component-as-a service (e.g. battery)
Market maker for circular inputs	OEMs, material suppliers and recyclers develop a platform to improve transparency for disassembly and recycling and bring together supply and demand for circular inputs such as remanufactured components, and recycled material. The platform connects all relevant value chain actors. The specifications of products relevant for recovery, as well as the available and required volumes of circular inputs are shared. Circular inputs can be exchanged through the platform.	– Circular material stock – Component-as-a service (e.g. battery) – Optimized component reuse and remanufacturing
Balanced production capacity	OEMs and parts suppliers maximize manufacturing capacity for success in the long term in the circular automotive industry. Large-scale and small-scale production, as well as new car/component manufacturing and remanufacturing/reconditioning facilities are finely balanced depending on the local demand. Excess production of new cars is prevented, hence reducing the pressure on new car sales, and supporting the success of new business models focused on extended life or product-as-a-service.	– Modularity for life-cycle optimization – Purpose-built vehicle – Vehicle on demand – Mobility on demand
Renewable energy at scale	Energy providers increase the supply of renewable energy for vehicle production and recharge (e.g., clean electricity, green hydrogen) as a way to decarbonize emissions from energy production. Governments invest in domestic infrastructure and increase the incentives for renewable energy production and storage options. Energy providers, OEMs, and mobility services collaborate on developing low-carbon generation solutions and renewable charging infrastructure.	– Low-carbon materials – Low-carbon production – Alternative drivetrain
Autonomous driving	OEMs, national and local governments will integrate autonomous driving within future mobility deployment scenarios. Autonomous driving will speed the deployment of vehicle-on-demand and mobility-on-demand business models and allow the adoption of these business models at scale.	– Vehicle on demand – Mobility on demand breathing fleets
Mobility platform	Mobility service providers mix different services (e.g., on-demand vehicle, on-demand mobility, micro mobility, public transportation) into a multi-modal platform. Customers are incentivized to take the greenest route wherever possible.	– Vehicle on demand – Mobility on demand breathing fleets

Accenture highlighted 5 business models in relation to circularity in automotive. To each of them it allocated the previously identified solutions and enablers (understood as technologies, innovations, new products, and market makers). Each business model has also been assigned the areas of the circular economy associated with it. Some solutions, enablers and transformation pathways have been matched to multiple business models. The solutions and the enablers were subsequently matched to the previously identified levels of circularity and associated with the relative transformation pathway. It can be observed that some solutions and enablers were associated to more transformation pathways.

4.1.3. Forging Ahead: A materials roadmap for the 'zero-carbon' car

The third report is titled "Forging Ahead: A materials roadmap for the 'zero-carbon car."[7] and was released in December 2020. This report developed in collaboration with McKinsey & Co, are reports projections of the costs and technology investments needed to decarbonize materials used by the automotive industry. The guidelines in this report support the transition to a market for scale to produce low-carbon materials. The emission in material production after electrification will be the main emitters in the vehicle's lifecycle. By 2040, they are expected to contribute 60% of a vehicle's lifecycle emissions.

4.1.4. Paving the Way: EU Policy Action for Automotive Circularity "Circular Cars Initiative"

The fourth and last report is titled "Paving the Way: EU Policy Action for Automotive Circularity CIRCULAR CARS INITIATIVE."[8] and released in June 2021. Businesses along the automotive value chain should mobilize policymakers to align upcoming measures with the CCI's collective vision and improve circularity principles. This report provides an overview of these measures:

- Expand performance assessment from exhaust emissions to a life-cycle perspective across the value chain to enable rational and effective policy and decision-making for the mobility and manufacturing sectors in general.
- Accelerate the use of circular and low-emission materials to scale demand and improve recycling markets, with a focus on metals, plastics, and battery materials.
- Refocus circularity on preserving the highest value processes by extending the practice from recycling to extending vehicle life through reuse and remanufacturing. Improve vehicle utilization by promoting fleet management and vehicle pooling.

4.2. How TREASURE relates to the areas of research and innovation highlighted in the trends.

The trends identified by the CCI have been taken as a reference and related to the project outputs. The KETs of TREASURE were then placed on the various levels of circularity highlighting the areas in which it will be able to contribute. They have been placed then on the relative business models, solutions, enablers, and transformation pathways.

4.2.1. How TREASURE relates to the levels of circularity

TREASURE can play its part in the transformational pathways of product decarbonization, material circularity and lifetime optimization, helping the industry achieve levels 2, 3, 4 and 5 of

[7] CCI, "Forging Ahead: A materials roadmap for the 'zero-carbon' car" (2020).
[8] CCI, "Paving the Way: EU Policy Action for Automotive Circularity "Circular Cars Initiative"" (2021).

circularity. Figure 17 shown where TREASURE can provide support to the transformation of the industry.

In a Level 2 circularity scenario carbon emissions and resource consumption are reduced. Durability and use are improved through greater value chain coordination. TREASURE can contribute to achieving the following goals:

- Recycled content in materials selectively increased thanks to the eco-design module that supports manufacturers.
- Cross value chain to improve recycling and high-quality recyclability, thanks to the platform that enables knowledge sharing between the various supply chain actors and the recycling and disassembly modules to support the decisions made by dismantlers, shredders, and recyclers and thanks to the Bio-hydrometallurgical material recovery processes, the digital twin, the cyber-physical system and the cobots that enable higher quality recycling at a lower cost.
- End-of-life treatment is also more carefully considered during the design phase, thanks to the eco-design module that allows manufacturers to implement disassemblability by design and use easily recoverable materials.

In a Level 3 circularity scenario, the entire vehicle lifecycle is optimized. Incentives are aligned across the value chain. Individual cars and fleets could reach this level sooner through substantial cross-value chain alignment. TREASURE supports the achievement of the following goals:

- Low-carbon materials and manufacturing technology are everywhere. TREASURE supports the achievement of this goal as technologies used in laboratory and industrial pilots, as well as circularity assessments, will provide results that move in this direction.
- High-quality end-of-life recycling is widely implemented, thanks to product passports and network collaboration. Sharing data in TREASURE about materials contained in products, although not a product passport, can still be seen as a step in that direction and in the future why not it could become a product passport.
- Materials-as-a-service solutions align ecosystem incentives. As material suppliers begin to adopt this business model, the platform developed in TREASURE can help track these materials and the various supply chain stakeholders will be able to trace them back to the rightful owners of those materials.
- Modular design facilitates upgradeability, disassembly, and remanufacturing. TREASURE's eco-design module will support manufacturers in making responsible decisions moving in this direction.
- Remanufactured components are, to the extent possible, used in the production of new vehicles. TREASURE's contribution to this goal comes from the AI of the disassembly module, which will be able to provide information to disassemblers about valuable components in a good enough state to be remanufactured.

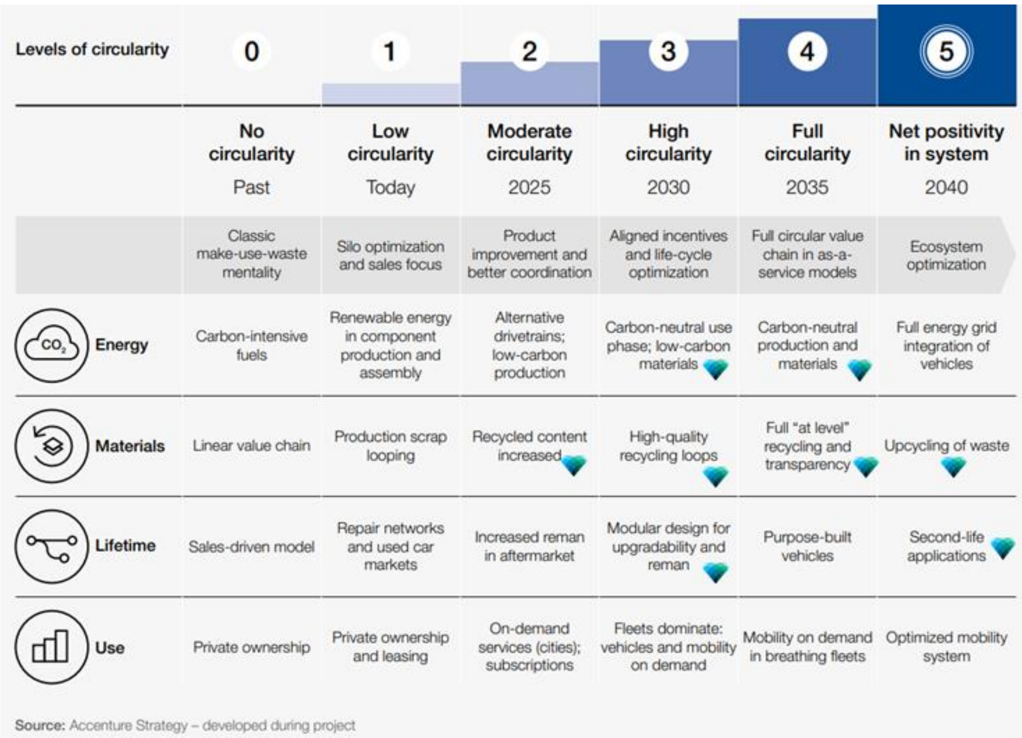
In a Level 4 circularity scenario, the value chain is fully circular, with no waste - meaning zero carbon emissions and zero non-circular resource consumption. Car design is closely coordinated with mobility providers and usage efficiency is optimized through fleet management. The entire value chain, from design to recycling, is highly optimized. To achieve level 4 circularity, the value chain, market structure and vehicle are transformed - in fact they are hardly recognizable. One challenge is to achieve scale and build a new value chain to support Level 4 circularity. TREASURE can help achieve these goals by:

- Laying the groundwork for carbon-neutral materials processing and manufacturing. Some early progress in this direction we hypothesize is seen in TREASURE's case study of prototyping structural electronics with the In-mold electronics process, assuming the energy sources are renewable.

- 100% of end-of-life materials are reprocessed or recycled within same-quality cycles. In TREASURE, 100% is not foreseen, but case studies of pilots will allow to demonstrate that it is possible to recover and recycle a good percentage of these materials and with a very good quality (same quality in the best-case scenario).
- Transparency and traceability are ensured, with standardized, global product passports. The same contribution TREASURE can make to achieve a level 3 circularity will serve as the basis for achieving this level 4 circularity goal.
- A significant proportion of the vehicle content consists of remanufactured components and recycled materials. The combination of the 3 modules developed in TREASURE will support the stakeholders of the value chain and allow them to reach this ambitious goal in the future.

In a Circularity 5 scenario, cars help optimize their surrounding ecosystem - improving the system-wide use of different transportation modes, upgrading materials, and improving energy networks. This means tight integration and alignment with adjacent ecosystems and convergence of business models and services. The overall system is highly integrated, optimized, and sustainable. Level 5 is an aspirational vision and can be developed in parallel with levels 2-4. TREASURE could help lay the initial groundwork regarding:

- The use of lower value materials or waste streams from other industries (e.g., end-of-life wind turbines). By expanding the platform to other industries, information can be obtained regarding the material content of non-automotive components. The recyclability module can then support recyclers in recovering those materials that can be used in the automotive sector.
- Suitable vehicle components, such as electronics, motors, or batteries, are enabled for external second-life applications at scale. The AI-supported disassembly module can provide disassemblers with information about the value of the recovered components, supporting them in selling these components to more profitable markets.



Levels of circularity	0	1	2	3	4	5
	No circularity Past	Low circularity Today	Moderate circularity 2025	High circularity 2030	Full circularity 2035	Net positivity in system 2040
	Classic make-use-waste mentality	Silo optimization and sales focus	Product improvement and better coordination	Aligned incentives and life-cycle optimization	Full circular value chain in as-a-service models	Ecosystem optimization
Energy	Carbon-intensive fuels	Renewable energy in component production and assembly	Alternative drivetrains; low-carbon production	Carbon-neutral use phase; low-carbon materials	Carbon-neutral production and materials	Full energy grid integration of vehicles
Materials	Linear value chain	Production scrap looping	Recycled content increased	High-quality recycling loops	Full "at level" recycling and transparency	Upcycling of waste
Lifetime	Sales-driven model	Repair networks and used car markets	Increased reman in aftermarket	Modular design for upgradability and reman	Purpose-built vehicles	Second-life applications
Use	Private ownership	Private ownership and leasing	On-demand services (cities); subscriptions	Fleets dominate: vehicles and mobility on demand	Mobility on demand in breathing fleets	Optimized mobility system

Source: Accenture Strategy – developed during project

Figure 17 Levels of circularity for which TREASURE can contribute

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4.2.2. How TREASURE relates to the enabler solutions

TREASURE was then related to the solutions and enablers that will enable various levels of circularity over time, as shown in Figure 18 . The contribution that it can give to the various solutions has been made explicit in the next sub-chapter, “§4.2.3 *How TREASURE relates to the circular business models* “. In terms of enabling factors, TREASURE can be related to:

- Recoverable and recyclable materials
  TREASURE can contribute to greater collaboration between OEMs, component suppliers and material suppliers. The eco-design module of the platform being developed in TREASURE will support the vehicle design process to improve the recoverability and recyclability of materials. Variability and complexity of the material mix in a car will be adapted to recycling processing options to maximize the recoverability and minimize the creation of residues based on detailed know-how of recycling technologies and requirements of input quality. This will impact the "Circular Materials Stock", and “End-of-life management” solutions.

- Product passport
  OEMs, component and material suppliers, and recyclers collaborate on the development and implementation of a product passport for vehicles and/or components and materials. TREASURE can contribute to this process by providing relevant information (e.g., origin, material composition). Data needs for the product passport will be defined such that these allow real calculation of recycling rates based on full product mineralogy. This is a key understanding with respect to data detail required that will be gained from the project. Not only that, but sharing this data allows for optimizing reuse, improving the rate and quality of recycling, and enabling better traceability. These enablers support the "Circular Material Stock", "Optimized Component Reuse and Remanufacturing", "Professional EOL Collection, Sorting and Reverse Logistics" solutions.

- Advanced recycling technology and infrastructure
  In TREASURE, advanced technologies and new recycling processes will be validated or developed to improve recycling rates and the quality of materials recycled from end-of-life cars. In addition, practical knowledge from OEMs, and material suppliers, will be integrated into TREASURE and pilot projects will be funded. These enablers are in support of the "Circular Materials Stock" solution.

- Market maker for circular inputs
  The platform developed in TREASURE enables better transparency on disassembly and recycling operations. In addition, it can be a meeting point between demand and supply of circular inputs (e.g., remanufactured components, recycled material). A two-sided platform connects all relevant value chain actors. The specifications of products relevant for recovery, as well as the required volumes and quantities of circular inputs are shared. Circular inputs can be traded through the platform. These enablers support the solutions of "Circular Material Stock", "Optimized Component Reuse and Remanufacturing".

- Balanced production capacity: new vs. remanufacturing
  The reconfiguration and optimization of TREASURE pilots, will enable knowledge transfer to OEMs and component suppliers, optimize production capabilities for long-term success in a circular automotive industry. With TREASURE, lessons can be learned for both large- and small-scale production, as well as new car/component production

and remanufacturing/remanufacturing facilities. These enablers support the solutions of " Modularity for Life Cycle Optimization", and "Purpose-built Vehicle".

- Balanced production capacity: small vs. large-scale
  In TREASURE, low carbon manufacturing options will be analysed and developed. This enabler supports the solutions of "Low Carbon Materials", and "Low Carbon Manufacturing".

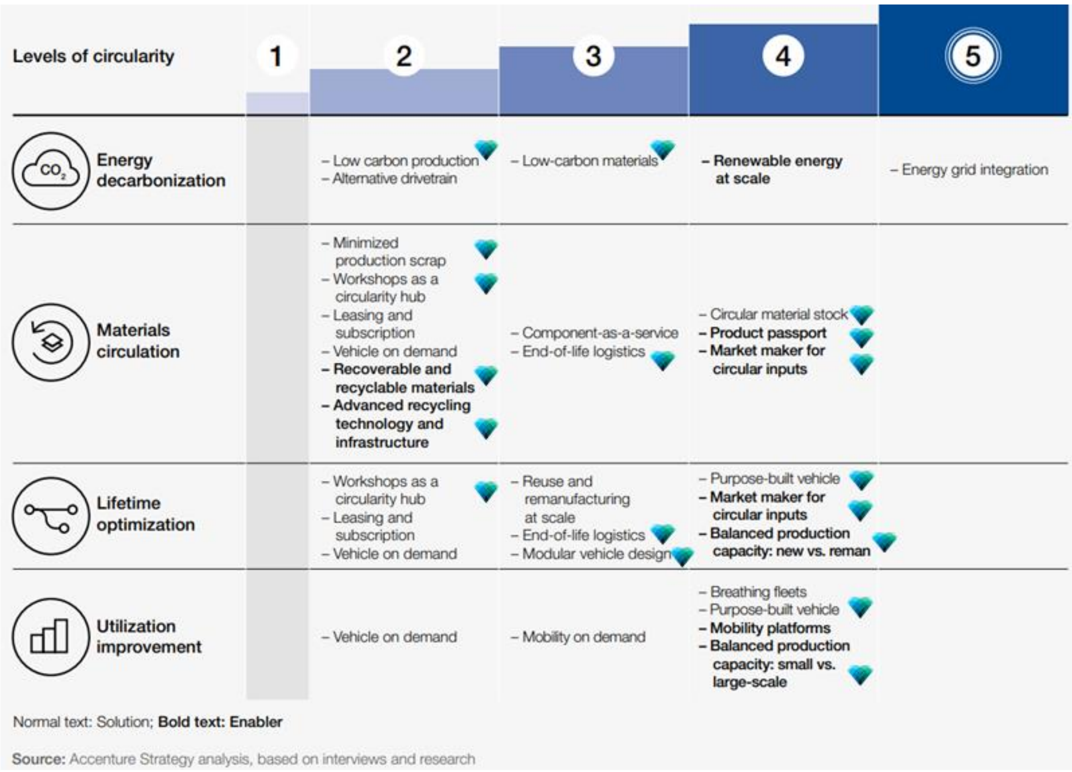

Figure 18 Solutions and enablers for which TREASURE can contribute

4.2.3. How TREASURE relates to the circular business models

Five major families of business models have been identified in the model developed by Accenture, and they are: Circular inputs, product-as-a-service, sharing platform, product use extension, and resource recovery. TREASURE can contribute to 3 of 5 of them. Figure 19 shown the areas of the business models where TREASURE can contribute.

It can address the **circular inputs business model** by encouraging the use of renewable, recycled, recyclable materials. TREASURE supports:

- Recyclers in adopting energy efficiency measures in recycling automotive materials, helping them to reduce CO_2 from materials. This support comes from the recycling module and is a direct result of MARAS' studies on the quality of recycled materials, the Bio-hydrometallurgical material recovery process first validated on the FENIX PCB disassembly station, and ILSSA's industrial pilot.
- OEMs and component suppliers to adopt energy efficiency measures in component manufacturing and vehicle assembly, with the eco-design module providing guidelines on disassembly by design and energy saving techniques.
- Material suppliers in the business of materials-as-service thanks to the aggregated information contained in the platform. Material suppliers can develop a stockpile of fixed-size material used and reused for cars, validating the principle of "same value loop

recycling." Waste (including downcycling) is reduced, and materials are recycled at the highest level by specialized recyclers supported by the recycling module. A starting point is to establish circular inventories for selected materials (e.g., aluminium). Materials-as-a-service enables closed-loop recycling of selected materials. In the best-case scenario of this solution, 100% of the materials in a car are circular. This means that non-circular inflows and outflows from the car are eliminated. CO_2 from materials is greatly reduced to lower the carbon intensity of recycled materials. CO_2 from end-of-life treatment is reduced.

TREASURE can help the **business model of the product use extension** through reuse, remanufacturing, and repurposing. Specifically, it can help:

- garages by reducing non-circular resource consumption and on lifecycle carbon emissions. Increased use of remanufactured components instead of new components reduces the non-circular influx of cars and reduces CO_2 from materials due to the lower carbon intensity of remanufactured components. This help is an indirect consequence of the disassembly module, in fact, disassemblers thanks to this module and AI, can identify valuable components suitable for remanufacturing, consequently increasing the remanufactured components on the market.
- OEMs and suppliers to cooperate to increase the efficiency of disassembly, sorting, and reverse logistics processes and enable recovery at the highest possible value. Components and materials are channeled to remanufacturing facilities with greater awareness. Non-circular car outflows are reduced, resulting in less CO_2 from end-of-life treatment. These improvements are coordinated by the platform, which thanks to the disassembly module supports disassemblers in recovery and guides them in their reverse logistics selection choices, and thanks to the eco-design module allows manufacturers to implement disassembly by design.

Finally, TREASURE can support **resource recovery business model** through closed-loop recycling of production scrap and end-of-life vehicles, but also open-loop recycling or even energy recovery. TREASURE facilitates:

- Cooperation between OEMs and component suppliers, helping them to collaborate with material suppliers to reducing total production waste leads to reduced CO_2 from materials. TREASURE's platform enables this cooperation through better and more transparent data sharing. The eco-design module helps manufacturers reduce production waste, helps them make decisions that optimize recycling rates, and helps them improve the quality of unavoidable production waste. Improved recycling of production waste reduces the amount of non-circular car outputs.
- Cooperation between OEMs, suppliers, and recyclers. They can increase the efficiency of disassembly, value selection and reverse logistics processes, thanks to the AI-supported disassembly and recycling module. Value recovery can thus be maximized, and this solution improves the circularity of outflows from end-of-life vehicles. Non-circular car outflows are reduced, resulting in less CO_2 from end-of-life treatment.

Business model archetypes	Circular inputs	Product -as-a-service	Sharing platforms	Product use extension	Resource recovery
Solutions	– Low-carbon material – Low-carbon production – Circular material stock – Alternative drivetrain – Energy grid integration	– Component -as-a-service – Leasing and subscription – Vehicle on demand – Mobility on demand – Breathing fleets	– Energy grid integration – Vehicle on demand – Mobility on demand – Breathing fleets	– Modular vehicle design – End-of-life logistics – Reuse and remanufacturing at scale – Workshops as a circularity hub – Purpose-built vehicle	– Minimized production scrap – End-of-life logistics – Circular material stock
Enablers	– Recoverable and recyclable materials – Product passport – Advanced recycling technology and infrastructure – Market maker for circular inputs – Renewable energy at scale	– Autonomous driving – Mobility platform	– Autonomous driving – Mobility platform	– Product passport – Balanced production capacity	– Recoverable and recyclable materials – Product passport – Advanced recycling technology and infrastructure – Market maker for circular inputs
Transformation pathways	– Energy decarbonization – Materials circularity	– Utilization improvement – Materials circularity	– Utilization improvement	– Lifetime optimization	– Materials circularity

Source: Accenture Strategy

Figure 19 Circular business model for which TREASURE can contribute

5. Conclusions

In this deliverable, the multi-dimensional reference framework developed for TREASURE project is described. First, the project architecture was depicted by identifying the relationships among both work packages and tasks in terms of exchanged inputs/outputs and exploited results, coming either from inside or outside project context. Upon the enhanced and shared project architecture framework, the circularity framework has been built: the Key Enabling Technologies to have been placed along the activity's flowchart and their main contribution to the enhancement of sustainability and technology performance was highlighted. The circularity framework points out also the connection between results from demonstration activities and exploitation of these results outside the project and incorporates the positioning of TREASURE results on the circular trends identified by the CCI in terms of levels of circularity and circular enablers and solutions. The last level of the framework addressed by this deliverable, the "TREASURE vs CE in automotive" level, gives evidence of the contributions of TREASURE solutions in the current state of automotive' s circular business models, providing a high-level input for the activities of WP8 related to the identification of new business models.

The criticalities emerged in this deliverable relate to the need for reliable and exhaustive data on material compositions as well as the compositions of scrap materials in the various processes of dismantling, recycling, and prototyping. The absence of quality information could affect a proper assessment of the sustainable scenarios. The availability of relevant data and their shareability within the consortium is another important critical point that will be addressed in T1.2.

The remaining two months of T1.1 according to DoA (it is expected to run until month 6) will focus on reporting the results of the workshop on the value chain digitalization framework, which will be furthered in T1.2. Moreover, the foundation for the "Partners and industry" level framework not covered yet in D1.1 will be laid. Indeed, possible criticalities for which there has been no evidence yet will be investigated, addressing solutions and responsibility of key partners based on their background knowledge, to provide the clearest overview of the consortium potentialities. The results of this analysis will be provided either on the Miroboard, which will act as a "living" board during the project activities, or as an introductory chapter on the future deliverables of WP1.

6. Abbreviations

AI	Artificial Intelligence
BEV	Battery Electric Vehicle
BM	Business model
BoL	Beginning of Life
CCI	Circular Cars Initiative
CE	Circular Economy
CPS	Cyber Physical System
CRM	Critical Raw Materials
DOA	Description of Actions
DT	Digital Twin
ELVs	End-of-Life Vehicles
EoL	End of Life
ICEV	Internal Combustion Engine Vehicle
IMSE	In-Mold System Electronic
KETs	Key Enabling Technologies
LCA	Life Cycle Assessment
M	Month
SoA	State of Art
T	Task
WP	Work Package

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